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TECHNICAL SECTION

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S. D. KIRKPATRICK . . *Editor*

MAY, 1937

McGRAW-HILL PUBLISHING CO., INC.

FLUIDS HANDLING

AN IMPORTANT UNIT OPERATION

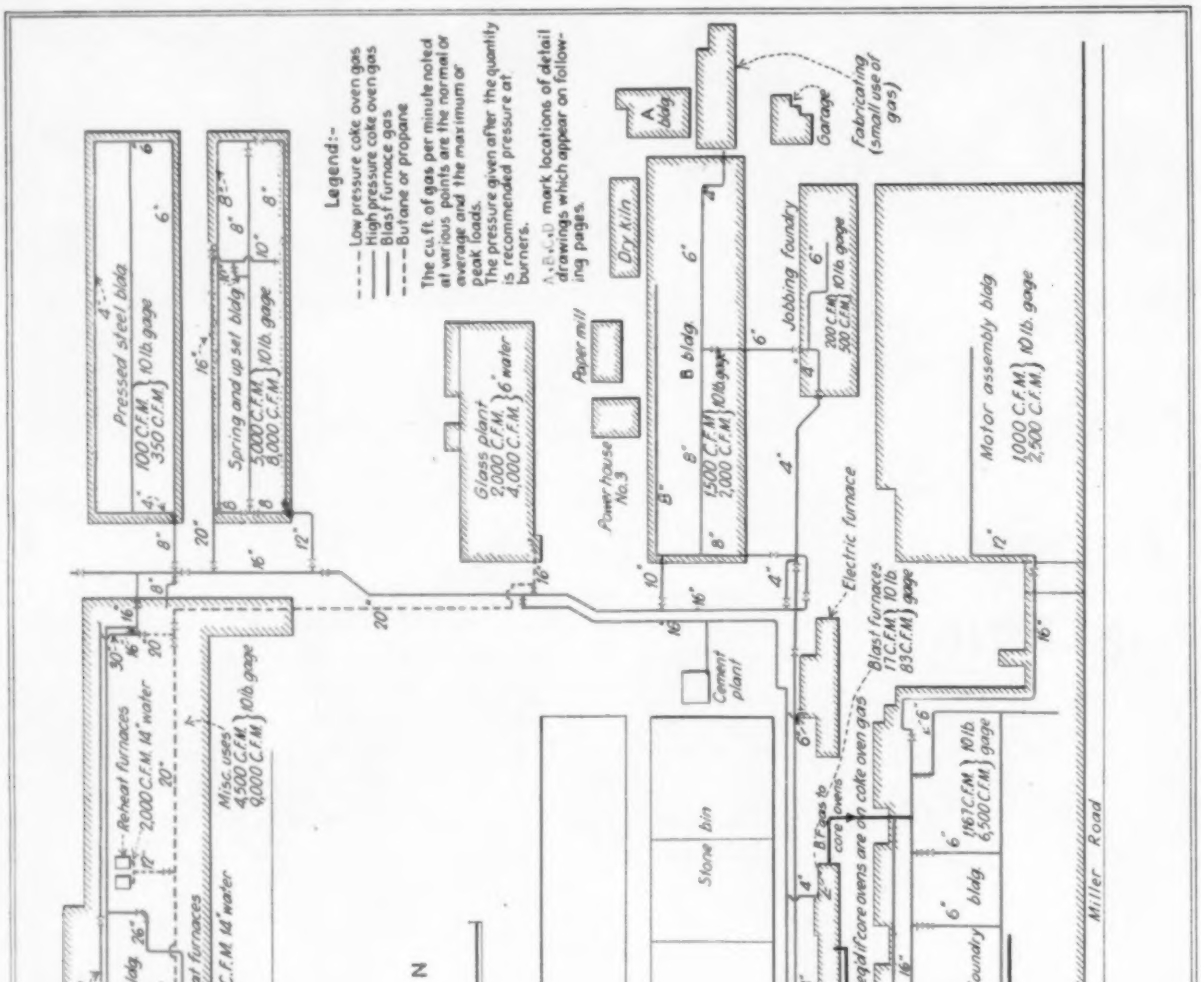
ALMOST every chemical engineering enterprise, large or small, involves the handling of some fluids. Modern industry usually finds it more economical and convenient to move materials in fluid form. Hence more and more of the work of the chemical engineer is concerned with the preparation, use, conveyance or storage of gases and liquids. Recognizing this important responsibility, *Chem. & Met.* presents in this issue a critical compendium of present theory and practice—of methods and equipment.

Fluids handling is of such far-reaching importance in all branches of the process industries that it might well have occupied many times the space available in this issue. Restriction of editorial treatment was therefore necessary. This has been accomplished in large measure by defining the term "fluids handling" to include only those definite physical operations in which no change of composition, purity, or chemical characteristic is desired.

A critical approach to these problems has been undertaken at all stages, mere description of a multitude of devices being avoided in the interest of simplicity and usefulness. Readers will necessarily go from these interpretive outlines in the various chapters which follow to their engineering handbooks, trade literature and research journals for details that are essential in each specific application. This issue will, it is hoped, serve as a preliminary guidebook, particularly during reconnaissance stages of research, development, design and operation, as the case may be.

Engineering work of this sort usually is preceded by a broad economic planning of the technical problems to which machinery and facilities are to be applied. So, too, in this issue the leading article by R. S. McBride is devoted to a description and critical analysis of one of the most elaborate gas-handling plants in America, a plant which certainly is in the front rank as to size in fuel-gas manufacture and utilization. It is hoped that this article will serve to stimulate in other establishments as careful, critical and comprehensive analysis of fluids handling as has been accorded by the engineering staffs of this works and the various engineering groups who have cooperated with them.

The balance of the issue was organized and executed under T. R. Olive's active direction. It begins with a competent attempt to rationalize our theoretical knowledge that it may be more useful in practice. Then follow extended summaries of the outstanding types of equipment or facility used for piping, conveying, compressing, pumping, controlling, storing, shipping and other physical handling of gases and liquids as they are used in the plants of the process industries. Viewed from any angle, there are no more universally important unit operations in chemical engineering practice than these. The editors of *Chem. & Met.* are proud to add this contribution to the long series that, in small measure, have helped bring about the more efficient planning and practice of chemical engineering in industry.



General plan of the Ford Motor Co.'s plant at Dearborn, Mich. showing the system of mains and line stations required to handle the fuel gas requirements of this large enterprise

An Industrial System for FUEL GAS HANDLING

By R. S. McBRIDE

EDITORIAL REPRESENTATIVE, CHEM. AND MET.
WASHINGTON, D. C.

Gas is just as important in the manufacture of automobiles as is "gas" in the tank to run them. In recognition of this, the Ford Motor Co. at Dearborn, Mich. is installing one of the largest industrial gas-generating and gas-distributing systems in the world. There are, in fact, only one or two utility companies which supply as much manufactured gas as this industrial works can make and burn. This article describes the planning and engineering analyses required to make this huge installation an efficient and effective part of the automobile plant it is designed to serve.

THE GAS SUPPLY system in the Ford Motor Co.'s works at Dearborn, Mich., is planned for coordinated production and use of several fuel gases. Some of the operations in the Ford plant cannot be effectively carried out at all without gaseous fuel. Some operations can use either oil or gas. For other purposes, coal is preferred as the cheapest fuel. Where gas is used it may be either a low B.t.u. fuel gas or, for operations that require a gas of higher form value, one of higher B.t.u. which permits more accurate control or the efficient achievement of higher temperatures.

The gas-supply system of this huge works takes careful account of these general facts and of many other more detailed considerations, some of which are discussed here. From the standpoint of the chemical engineer, greatest interest lies in the careful technical analysis which was made and the thorough economic planning then accomplished as a preparation for the technical work. These preparatory steps are just as important as are the choices of equipment or facilities which enter as units in the complete system.

In the following discussion the effort is made to present fully these broad considerations in the belief that the forethought and systematic study which formed the basis for this huge automotive gas-using enterprise might offer the reader some valuable suggestions applicable to his own projects.

A Ford automobile cannot be made of the requisite quality without using in this one works at least 25 million cu.ft. per day of fuel gas having 500 to 530 B.t.u. per cubic foot. Many other operations, for which gas is not deemed "essential," also can be most economically carried out with gas. As soon as the present plan for gas generation and gas handling has been completed, this works will regularly employ in excess of 50 million cu.ft. and may, on occasion, use as much as 75 million cu.ft. This establishment has at its single gas "switchboard" complete control of this huge quantity of gaseous fuel.

Not all of the gas supply is of the high heating value indicated, 500 B.t.u. Much of it is of lower energy content. On the completion of the present project there will be available per day: Coke-oven gas, 500 B.t.u., 54 million cu.ft.; Blast-furnace gas, surplus not required in furnace department, 100 B.t.u., 180 million cu.ft.; Butane gas, 3,200 B.t.u., 2 million cu.ft.; Producer gas, volume not yet determined. In aggregate, this gaseous fuel contains in excess of the equivalent of 90 million cu.ft. per day of 500-B.t.u. fuel gas. Such a supply through an ordinary utility system would care for well over a million average American families, or for household and commercial needs of a city having a population of 4,800,000.

Even with these huge quantities of gaseous fuel regularly available, the energy requirements for this works are not fully met. For power generation, firing of a wide variety of industrial furnaces, and for incidental plant heating operations, this works on the average day also consumes: Coal for boilers, 2,000 tons; Coal for coke ovens, 4,500 tons; Fuel oil for forges and steel mill, 80,000 gal.; Coal tar, 40,000 gal.

It is interesting to note that the ultimate set-up for fuel-gas supply in the single works at Dearborn represents a contemplated "send-out" well in excess of the

average day's sales of the Detroit City Gas Co., one of the largest public-utility purveyors of fuel gas in the country. Moreover, the effective storage capacity for gas within the Ford works exceeds the total gas-storage capacity of this local utility enterprise, although the latter has approximately 58 million cu.ft. of holder space.

Two Sources of Gas Supply

Two systems of gas supply are employed, one based on blast-furnace gas, the other on coke-oven gas. The blast-furnace gas supply, of about 100 B.t.u. per cubic foot, materially exceeds the requirements for the hot-blast stoves in the metallurgical plant itself. The surplus is, therefore, taken for other heating operations where the highest temperature or most closely controlled furnace conditions are not necessary. In those applications, the low form value suffices; but even there, reasonable uniformity in burner characteristics is desired. In order to insure this desired uniformity, arrangement is made to enrich the blast-furnace gas by adding coke-oven gas or, rarely, butane gas. This brings it up to a standard heating value, at present 100 B.t.u. With this arrangement, it is no longer difficult for the "customer" departments within the works to maintain their operations with uniformity, even when the blast furnaces may temporarily be making a leaner gas.

The richer fuel supply, which has coke-oven gas as its base, is at present uniformly available at about 530 B.t.u. per cubic foot, which was formerly the highest heating value regularly maintainable. But the new coke-oven installation which was put into operation during February makes possible a higher B.t.u. standard if necessary. Such higher standard is, however, not now desirable. In fact, it is contemplated that a slightly lower B.t.u. gas would probably be preferred for some purposes. Therefore, it is likely that the rich fuel-gas lines will soon carry a 475-B.t.u. supply. It will be made by diluting run-of-oven gas with just enough blast-furnace gas to hold the supply constant at this value, which is just below the minimum at which the ovens will ever operate.

Uniform quality of gas in both high and low heating-value systems is maintained by automatic calorimeter control. A Calori-Mixer takes a continuous sample of the mixed gas from each system. When the heating value is either above or below the predetermined range of quality required, this calorimeter furnishes the electrical impulse for actuating the Askania units. These regulators in turn, open or close by the requisite amount the butterfly valves at the mixing stations. The rich gas is to be held at 475 B.t.u. plus or minus 3 B.t.u.; the lean gas between 95 and 100 B.t.u. The accompanying mixing station diagram indicates the interconnection of these facilities.

The importance of this system for quality control of gas send-out is no less in this motor works than it would be on a public-utility distributing system. Efficiency of use in the various customer departments can be best maintained only when the fuel supply transmitted does not vary from day to day or from hour to hour in its performance characteristics. The elaborate and expensive control facilities here installed are, therefore, more than justified by the improved utilization results obtained. In fact, on many industrial systems that are much smaller such equipment would undoubtedly pay its way many-fold.

In addition to B.t.u. control, it has been found desirable lately to observe and record gas specific gravity. As yet, no automatic facilities for specific-gravity adjustment have been installed. In fact, such control automatically may not prove feasible. But it has been determined by the plant engineers that an unusual variation in the gravity of the gas is quite as disturbing at the user department as would be a variation in heating value. The reason is obvious when one considers that burner behavior of fuel gases is largely determined by the mass (not volume) of the gas which flows through the inspirator type of burners.

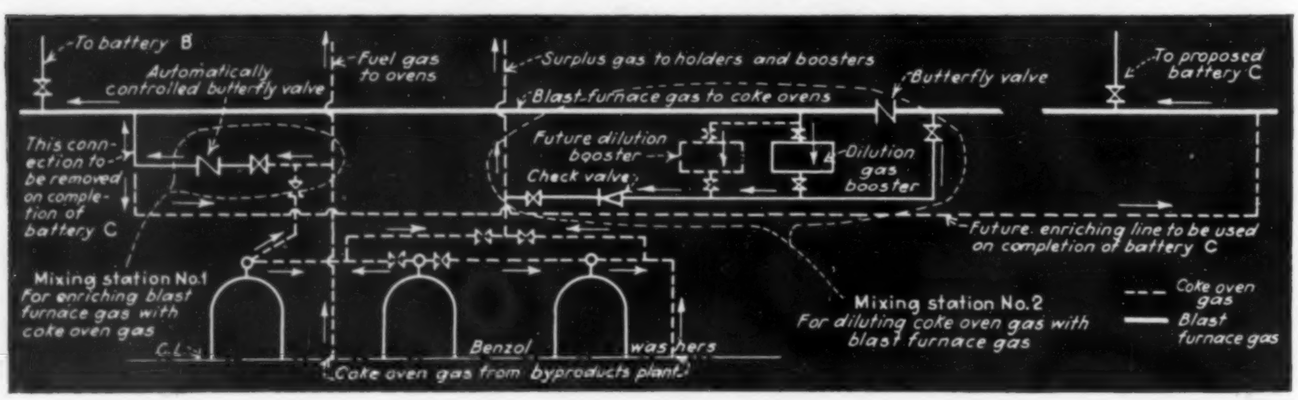
Fluctuation of Consumption

Flexibility in plant operation is of unusual importance in this works because many of the gas-using operations are carried out only five days a week. From Monday to Friday there is never enough gas to go around; but on Saturdays and Sundays there is a huge surplus from the base-load units which supply high heating-value gas, as this is the supply which goes into departments for motor and parts manufacture and car assembly.

There is less fluctuation in the low heating-value system. Production at the blast furnace is, of course, practically constant. And most of the user units require this fuel gas seven days a week, though not all for 24 hours a day. But even in this low-B.t.u. system, great flexibility is required and a "dump" for surplus must be provided. Naturally, the boiler house is always available for this disposal of surpluses. But other features have been worked out in order to minimize that means of disposal. The economic reasoning is evident from the following facts.

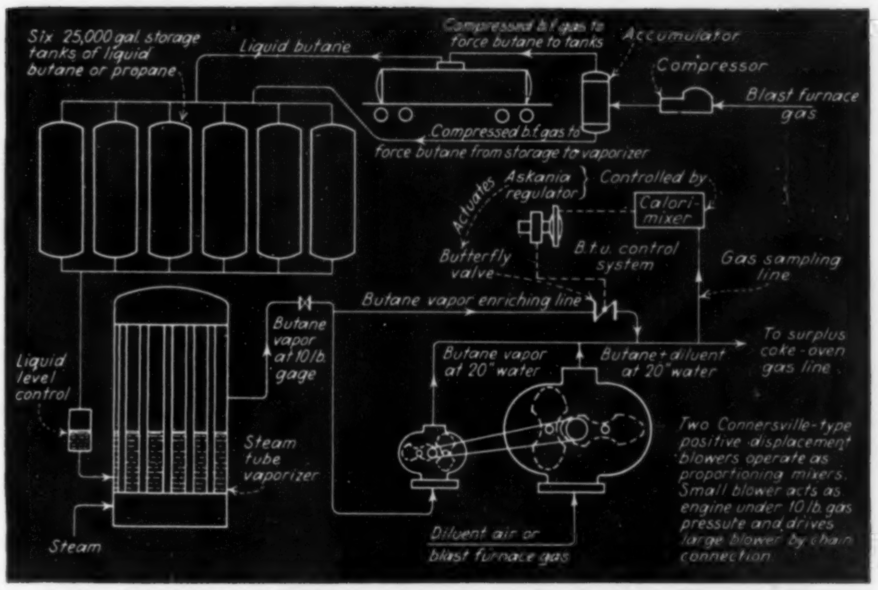
In this works when gas is used to supplant coal, as for steam raising in the power plant, the energy is worth only

A—Enlarged plan of gas-mixing stations Nos. 1 and 2. Automatic calorimeter-controlled mixing valves maintain a uniform quality of gas in both the high and low heating value systems



about 18 cents per million B.t.u. In other sections of the works where gas commonly supplants oil, the equivalent fuel worth is 30 cents per million B.t.u. But generally, gas is rated at about 40 cents per million B.t.u. throughout the average applications where it has operating advantages over oil.

It is interesting in this connection to note that when butane gas is employed it enters the system at about 52 cents per million B.t.u. But even at this higher apparent cost, it contributes to over-all economy. As a matter of fact, it does this most importantly because of its tremendous advantage in furnishing an emergency reserve with a minimum capital requirement.



B—Mixing station No. 3 (butane station)—for enriching coke-oven or blast-furnace gas with butane or propane; also serves as a reserve unit for supplying gas to plant during blast furnace or coke oven shutdowns

Storage of temporary surpluses, especially over the week-end, will be in part provided for on completion of the new 10 million cu.ft. waterless gas holder now being erected. It will function on a weekly cycle, starting Monday morning filled to the limit with the coke-oven gas. For each of the next five days the works requirements during day and evening shifts will use from the holder 6.6 million cu.ft. and the ovens make only 4.6 million available surplus on the night shift. The difference represents approximately 2 million cu.ft. of consumption per 24 hours in excess of the productive capacity available from the ovens. By Friday night, the holder will, therefore, be practically empty.

During the week-end the discontinuance of many manufacturing and assembly operations will permit rebuilding the stock in the holder up to full capacity. In fact, the week-end surplus at the ovens will exceed holder capacity and some of this gas will then have to go into operations where low form-value fuel would serve equally well. Balancing of requirements will, however, keep this somewhat wasteful depreciation in service down to the minimum practical level.

Butane for Emergency Demands

Storage of blast-furnace gas in large quantity is neither necessary nor feasible. Nevertheless, a waterless holder of 2.5 million cu.ft. capacity is being installed to float on the furnace-gas line in order to iron out short-time variations in production at the furnace—while changing a tuyere, for example. When surpluses are available in this system they are disposed of at the boiler plant. When there are shortages they may be made up by substituting higher heating-value gas for some furnace-gas operations, butane stand-by equipment may be put into service, or more oil may be used. The choice depends on prevailing conditions, the character of heating operation involved, and the prospective interval during which the new condition will prevail.

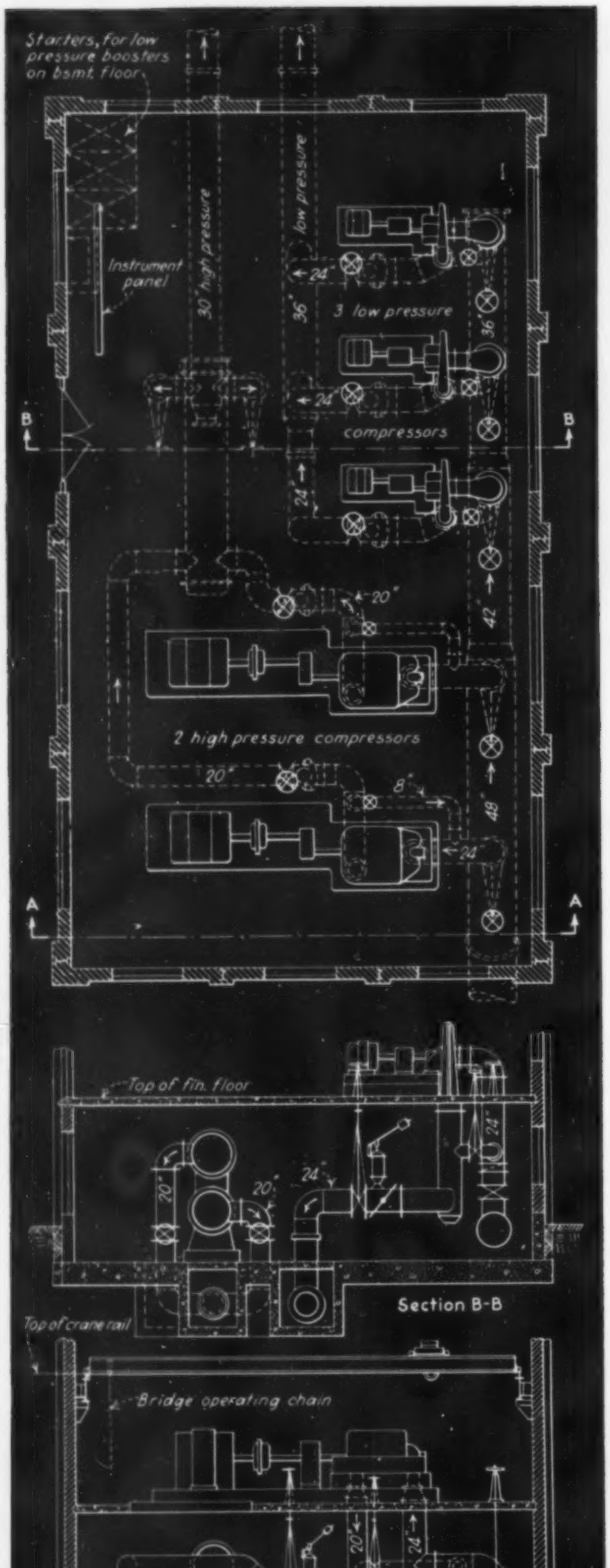
As an emergency reserve to prevent failure of gas supply in the works when either the blast furnace must be down completely or the coke ovens cannot function at anticipated capacity, there has been provided a butane-gas installation. This is equipped to gasify per hour as much as 200,000 cu.ft. of butane.

This reserve system is equivalent in capacity to 3,200,000 cu.ft. per hour of 500-B.t.u. coke-oven gas. In an emergency all three batteries of ovens could be slowed down and the butane-gas unit could pick up the load of the rich fuel-gas system. Such a contingency is not anticipated, but is, nevertheless, provided for. And incidentally, this provision gives also the facility for supplanting the blast-furnace gas system should it be desirable at any time to take either or both blast furnaces out of blast for an extended period.

It is of special chemical-engineering interest to note that the installation required for this large butane-gas capacity has required a capital investment of only $100,000. This is less than one-tenth of the cost of the larger waterless holder, although the latter, of 10 million cu.ft. capacity, holds only one-third of the gaseous energy which the butane-gas system can supply daily. From these capital cost factors, one can understand why the higher operating expense per million B.t.u. is not a deterrent to the use of butane gas in the coordinated system.

Butane-gas production in this works may be carried out with either air or blast-furnace gas as the diluent. In either case the liquefied petroleum gas is vaporized in steam-tube vaporizers and fed at several pounds pressure to the mixing units. When this high heating-value gas is to be mixed with air it furnishes power for the mixer unit. This is accomplished in a novel fashion by direct chain drive between a small Connersville compressor and a large unit of the same positive-displacement type.

The high-heating-value gas under 10-lb. pressure drives the small unit handling 4,000 cu.ft. per minute, which in turn motivates the large unit that takes up air for the mixture at about 15,000 cu.ft. per minute. Thus the ratio between vapor and furnace gas or air, discharged at 20 inch water pressure, is maintained absolutely constant. Furthermore, the mixing operation stops if the



pressure on the butane vapor line fails. Thus there is no chance for the fuel-gas system to suck in a surplus of air and form mixtures within the range of explosive limits. This latter hazard might exist if the air unit were moved with an independent drive.

When butane vapor is mixed with blast-furnace gas, there is no corresponding danger of formation of explosive mixtures. Hence, the normal type of double butterfly valve operation would suffice if desired, to produce the required proportions, usually a 5:1 ratio. Whatever diluent gas is being used with butane, a Calori-Mixer with Askania control on the butterfly valves serves to maintain constant heating value in the send-out gas. It should be understood, of course, that this mixture is normally rich gas used to augment or supplant coke-oven gas at approximately 500 B.t.u. per cubic foot. But also butane gas can be used to enrich the blast-furnace gas if it falls materially below the desired 100 B.t.u. per cubic foot.

One great advantage of this installation as it is used at the Ford plant is the fact that butane or propane, or any mixture of the two, can be satisfactorily employed. The Ford works is, therefore, a preferred customer of the liquefied petroleum purveyors. They may use this large storage capacity as sort of a dump into which to put any one of their products which may happen to be in surplus, since any of them is satisfactory for use in the vaporizing and mixing equipment, and the settlement is based on total heat supply, not on gallonage or gas volume.

Firing of Coke Ovens

Under-firing of coke ovens of modern types can be accomplished with almost any fuel gas from 100 B.t.u. per cubic foot up. The three batteries of Becker ovens contemplated for the completed system at Dearborn have been designed with the maximum of under-firing flexibility. On very short notice a change-over can be accomplished from lean blast-furnace gas to rich coke-oven gas.

At one stage of the planning, it was even contemplated that the ovens would be fired five days a week with producer gas and two days a week with oven gas. But that plan is not essential, since interchanging of rich and lean gas on other parts of the system may prove to be more economic and convenient than this weekly shift to and from the richer under-firing gas.

The blast-furnace gas surplus has in the past been supplying primarily the heat for the core-drying ovens in the foundry building. These ovens use this fuel advantageously, even though of low form value. When the three batteries of ovens have been completed, blast-furnace gas will not quite suffice for under-firing the three batteries, even discontinuing the service to the foundry. It has been necessary, therefore, to analyze the possibility of installing a battery of five or six producers in order

C—Coke-oven gas compressor station. This station receives gas from the holder at 18 in. water pressure and boosts it to 2 lb. and 10 lb. ga. respectively for the low- and high-pressure distributing systems

A close check on all factors affecting the operation of the station is provided by an elaborate system of control and indicating devices

to supply more lean gas for under-firing the third battery. This plan would also permit continued use of lean gas at the core ovens. Ultimately, such installation will probably be made, although decision to that effect has not been reached.

The advantage of the producers as an alternate to the blast furnace is obvious. The gas is of similar burner behavior, low in heating value and high in inerts, nitrogen and carbon dioxide. Almost complete interchanging between producer gas and blast-furnace gas is, therefore, feasible. Furthermore, gas producers can be started up or shut down on a few minutes notice if kept banked under fire; and in a few hours even a cold producer can be on the line generating at full capacity without endangering the equipment while heating up. If such producers are installed, the three batteries will be under-fired from the lean gas system, and all present low-temperature heating operations around the works which have been using blast-furnace gas can be continued on this part of the fuel system.

Gas requirements throughout the works vary greatly in type and magnitude. On the general plat of the works are indicated in proper geographic relationship the major points where gaseous fuel is used. That plat shows an idealized arrangement which would be maintained regularly if constant plant operations permitted. Under those circumstances, the typical works requirements for gaseous fuel and oil would be as indicated in the accompanying table.

At each point of application there is competition between low B.t.u. and high B.t.u. gas, as well as between the supplies of the latter at low pressure and at high pressure where both are available. At each point the decision as to what fuel shall be used is made by the chief of the furnace and oven department. Not only relative cost per B.t.u. enters. The decision rests rather on the over-all advantage to the works. The final criterion in any decision is the effect on the ultimate cost of the Ford automobile.

Normal Gas Demands

Summary of major uses for which gas is preferred, in thousands of cubic feet:

	Normal	Peak
Blast-furnace gas:		
Hot-blast stoves	324	
Coke ovens, battery A	312	
Coke ovens, battery B	312	
Coke ovens, battery C	312	
Core ovens	336	
Power house	any surplus	
Total	1,596	
Low-pressure coke-oven gas:		
Soaking pits *	270	270
Reheat furnaces *	540	600
Glass plant	120	240
Open hearths (not in total)	0	1,500
Total	930	1,110
High-pressure coke-oven gas:		
Steel mill	270	540
Pressed steel building	6	21
Spring and upset forgings *	300	480
"B" building and fabrication	90	120
Jobbing foundry	12	30
Motor building	60	150
Foundry	70	390
Blast furnaces	1	5
Locomotive repair, etc.	1	5
Total	810	1,741

* Oil can be substituted in these places.

Compressor Station

Moving the quantities of gas involved in this distributing system requires quite a variety of compressing equipment. In the old installation the exhausters of the byproduct coke department were augmented by a battery of eight steam-driven reciprocating compressors, originally designed to operate at about ten or twelve pounds. Their capacity has, however, been increased in effect by operating to supply gas through the old distributing system at 15 to 18 pounds pressure. Since less than 18 pounds was inadequate to maintain the desired supply of 30 million cu.ft. per day at adequate pressure at the remote points in the works, a new compressor station has been designed. This, for economy's sake, will supply both high-pressure (10-pound) and low-pressure (2-pound) distributing systems, as indicated on the plant plat.

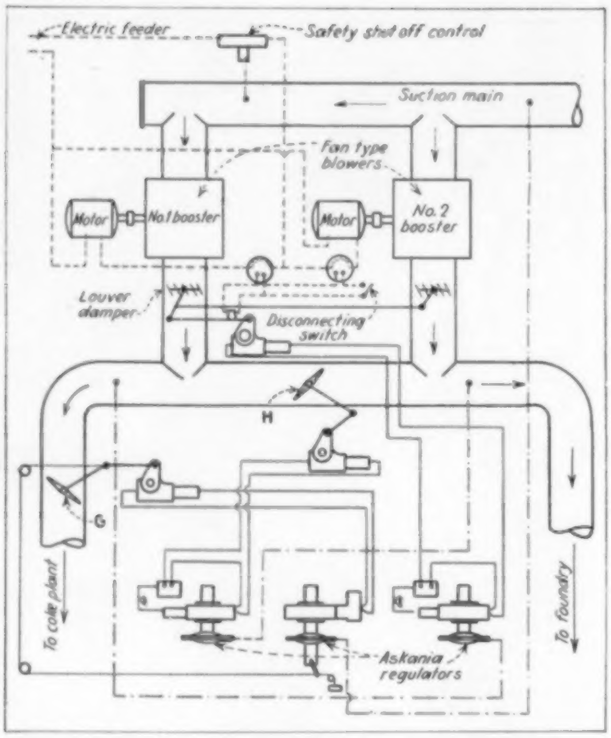
It required a very careful engineering analysis, first of the uses contemplated and secondly of compressor efficiencies, to determine how to proportion the new installation. It was obvious that a balance should be struck between pressure at the compressors and sizes of pipe lines to convey the gas to destination. The choice of two different pressures for the same high heating-value gas is the result. This combination affords a minimum over-all cost, which is made up of three main cost items: capital charges on compressor equipment, capital charges on distributing system, and operating expense for power to run the compressors.

The new compressor station will increase the gas-handling capacity from 36 to 56 million cubic feet per day for the oven-gas system alone. Two high-pressure and three low-pressure Allis-Chalmers turbo blower units are being installed. Their intake is a 48-inch line newly constructed across the south end of the plant, running from the oven section through a 13-foot diameter underwater tunnel. This is approximately 90 feet below yard level and runs 600 feet under the shipway slip. The discharge from the compressing units is into the two new lines that complete the loop system of the fuel-gas mains.

The new big holder which floats on this line throws a pressure of 18 inches of water. In emergency this pressure would suffice for the low-pressure gas-burning units in some customer departments. However, this pressure would not be maintained at the more distant points, the glass plant for example, because the intervening transmission mains are too small to operate at this pressure. About two pounds from the low-pressure compressors is required here to maintain a minimum of 14 inches at the more remote points on this distributing system.

Modern turbo blowers of the type designed for this work are so much more efficient than the old reciprocating equipment, that the new installation has substantially the full compressing capacity required for the two systems of distributing lines. But the old compressors have not been abandoned. They represent valuable stand-by capacity, adequate to take over practically the full load in case of need. In addition, they provide for maintenance of the pressure on their side of the loop distributing system.

Under these circumstances the new equipment could be made of barely sufficient capacity to take care of *minimum* normal gas loads. For greater demands, very commonly experienced, one or more of the old compressors can be put into service. It is anticipated that under most circumstances one or two old units will function



D—Blast-furnace gas booster station and controls. Valve *G*, controlled by the pressure in the suction line to the boosters, closes when the suction drops to 3 in. water pressure. Valve *H*, controlled by the pressure in the discharge line to the foundry, opens when the pressure in the foundry line reaches a predetermined point and thus allows gas to bleed into the line going to the coke plant only after foundry requirements are met

during practically all of the time when the manufacturing and assembly operations are going on, which means two shifts per day, five days a week, in busy seasons.

Compression of the blast-furnace gas for fuel usage has not been necessary in the past when this moved principally to the boiler house and core ovens of the foundry. However, it has proven economic when planning to under-fire the battery with this lean gas to install a booster station as indicated near the furnaces in order to reduce the size of pipe-line required for transmission to the major points of use at the ovens. One of the accompanying charts diagrams this installation, which is housed in the same building with the dispatching equipment. It consists of two fan-type blowers handling 30,000 cu.ft. per minute with an outlet pressure of 20 inches of water.

Piping System

The pipe lines in the works before the present modernization program began represented an expensive installation, in good condition generally, but one that had grown more or less like Topsy. One of the most important engineering services rendered by cooperating companies was, therefore, the adaptation of this old equipment to the new and complete layout with a minimum of loss on old lines that were in good condition. The major change found necessary was in the completing of a loop in the distributing system so that all of the major user departments could be served from either direction.

This loop development, which required about a mile of large new line, has many advantages. It minimizes the necessary size of pipe line. It permits the cutting off of a pipe line at any point for necessary repair or new installation without interrupting the service, since the gas can flow around the loop in either direction up to the point where work is going on. It provides the greatest flexibility in supply capacity, since abrupt changes in gas consumption at various points on the system introduce a minimum of inconvenience to neighboring departments. And most important of all, it has permitted the use of old compressor equipment for stand-by purposes and required the very minimum of new installation.

New transmission pipe lines have, as a result of careful planning, represented only a fraction of one per cent of the total cost of the modernization program. Far greater percentages have gone into holders, compressors and control equipment.

Central Dispatching Control

Dispatching of gas is one of the distinctive features of this installation. Over-all economy is the objective. Thermal efficiency in one department must not be permitted at the expense of greater cost increase elsewhere. Centralized planning is the first requirement; but actual physical control of supply by the dispatcher is regarded as equally important. The various department heads not only take orders from headquarters as to what gas they shall use, and when and how. Their supplies are also subject to absolute physical control from the central switchboard, which can at any moment cut off their gas by mere turning of a small switch at the dispatching table.

Centralized control such as this would not be safe nor economic without placing at the central station complete facilities for instantaneous appraisal of gas operations throughout the entire works. To furnish this information, there is an elaborate set of Bristol telemetric gages showing pressures and rates of flow at each strategic spot and the amounts of gas in storage throughout the gas-distributing system. A dispatcher sitting comfortably in his office knows exactly how much gas is flowing to each department, whether the pressure in supply lines is adequate, too low, or excessive; and the little indicators on his dispatching table show him the open or closed position of every important master valve. Every action in dispatching is, therefore, taken with the full knowledge of prevailing conditions in each of the individual departments drawing from the system.

Schooling contemplated for the dispatchers will insure that their decisions take adequate account of the effect of every manipulation they make for augmenting or cutting off supplies throughout the works. Inter-department telephone service will provide for prompt communication. But if oral orders are not promptly executed, the dispatcher, by a flick of a button, can close the valves which laggard operators have neglected to manipulate. Furthermore, no departmental operator will be able to open such a valve until this central dispatching point has released it with a return of the control mechanism to the open position. Actual opening of valves is, for safety reasons, necessarily carried out by the operator at the point where the gas is being used. A valve must be released *for* opening by the dispatcher, but cannot actually *be* opened by him.

FLUIDS HANDLING

ONCE AGAIN *Chem. & Met.* gives extensive technical treatment to one of the most important of the unit operations of chemical engineering. This time the editorial theme concerns the handling of fluids, a subject which is of fundamental application in practically every division of the chemical engineering field. How to design a system for flowing fluids, what is available in the way of pumps, compressors, piping, valves and accessories, how the pressure and flow of fluids are measured and controlled, how fluids are handled in storage and transit—these are some of the subjects touched on here. In a field so enormous, the forty-eight pages that follow can be no more than a beginning—even though condensed and compressed to give, in useful form, only the most important of the material available. At least it is hoped, however, that this will prove a palatable sample of what might have been published had we had many times this space.

Fluid Friction in Conduits

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EDITOR'S NOTE: In recent years engineers have come to realize that the empirical formulas developed to connect pipe size, fluid character and pressure loss in flowing fluids are often misleading and certainly confusing to anyone who does not use them constantly. Fortunately rational methods for making fluid-flow calculations have been developed, greatly simplifying work of this sort. As one of the co-authors of the Flow of Fluids Section of Perry's "Chemical Engineer's Handbook" and as an engineer who has done as much as any other to put the rational method on a working basis, the editors are pleased to have Mr. Genereaux introduce our symposium with this informative paper.

AMONG THE UNIT OPERATIONS of chemical engineering, probably the most consistently present, and therefore generally most important is the flow of fluids. The economics of the flow of fluids is of great and frequent application to industrial processes.

The selection of the diameter of pipe for greater economy under given flow conditions is often made by considering arbitrarily a narrow range of velocity as the optimum. This "velocity method" is generally and approximately correct for such commonly encountered fluids as water, air, and steam. The application of this "velocity method" to other fluids may cause erroneous results and so cannot be recommended for general or promiscuous use.

The purpose of this article is to simplify certain problems of fluid flow by offering rational formulas based on fundamental principles. In addition, a rational method for determining the economic size of pipe for given conditions will be described.

In the majority of cases encountered in plant design, the requirements of accuracy are governed by certain conditions, some of which are enumerated below. Commercial pipe and tubing are fabricated in certain standard inside diameters. It will be demonstrated later that it is economical to select an actual pipe size larger than the accurately calculated size, rather than one smaller. It is rare in plant operation that flow conditions are known with great accuracy. Consideration of these conditions leads to a conclusion that in most plant design problems, *there is more to be gained by being on the economical and "safe side" than to strive for great accuracy.*

Attaining desired results in engineering design is based upon intelligent use of the available information. In the field of fluid flow we have at our disposal the results of many theoretical and experimental investigations which, when properly applied, enable us to solve most of our problems with a minimum of error. Flow phenomena may be completely expressed in mathematical form when the data fully substantiate the theory, all the variables concerned having been considered. When the theory does not fully substantiate the data, rational methods of correlating the data are used to obtain the most adequate equations pending complete reconciliation with theory.

That portion of the subject of fluid flow which deals with steady (constant weight rate) flow in conduits is the most common in chemical engineering design. It is more fully understood when approached from the fundamental viewpoint which considers all the variables; the resulting methods are applicable to all fluids.

Reynolds Number and Friction Factor

The greatest impetus was given to this subject by Osborne Reynolds in 1883. His investigations of flow in cylindrical conduits demonstrated two types of flow, commonly designated as viscous (or laminar or streamline) and turbulent, separated by a "critical region." By means of dimensional analysis he derived a law of similarity which expresses the fact that flows in geometrically similar vessels are mechanically similar when they have the same value of $DV\rho/\mu$, a dimensionless relationship, now called the Reynolds number. By plotting a sufficiently wide range of pressure drop data on logarithmic coordinates with Reynolds number, *Re*, as the abscissa and the friction factor, *f*, as the ordinate, the types of flow mentioned above are indicated graphically, as in Fig. 1. The friction factor is also a dimensionless group in the form

$$f = 2gD\Delta P/4L\rho V^2 \qquad (1)$$

For Reynolds numbers below about

2,000, the data fall on a straight line with a slope of minus one. This is the viscous region. The relationships involved were determined independently by Hagen and Poiseuille in 1839 and 1840, respectively. (This relationship is variously called Hagen's law, Poiseuille's law, and more correctly the Hagen-Poiseuille law.) It is independent of pipe wall roughness but holds for circular pipe only. It can be stated as

$$\Delta P = 32\, \mu L V / g D^2 \qquad (2)$$

and can be obtained from Fig. 1 by substituting for f in Equation (1) its value

$$f = 16\, Re^{-1} = 16\, \mu / D V \rho \qquad (3)$$

which states mathematically the viscous line, A, of Fig. 1. The substitution results in

$$2gD\Delta P/4L\rho V^2 = 16\, \mu/DV\rho$$

and by simplifying and solving for ΔP, Equation (2) is obtained. This equation can also be derived from Newton's differential expression for viscosity[17].

By referring again to Fig. 1, it can be seen that the values of f increase as the Reynolds number increases from about 2,000 to about 4,000. This Reynolds number range is known as the "critical region" or "transition region". No attempt is made to formulate any relationship for this region because it is normally narrow in extent, its values depend upon pipe entrance conditions, and vibration of the pipe tends to accelerate the transition from viscous flow. Under the usual plant conditions it is safe to assume it part of the turbulent region. The term "critical velocity" is generally understood to mean that average linear velocity above which a given fluid at a given temperature and pressure, flowing in a given apparatus, will move in turbulent flow.[11]

As the Reynolds number increases above the critical region the flow becomes turbulent and the values of f decrease, but at a more gradual rate than in the viscous region. The resistance to flow becomes dependent also upon the pipe wall roughness. A considerable quantity of pressure drop data on flow in the turbulent region has been published and when plotted on the friction factor versus Reynolds number basis, present what at first glance appears to be a maze of points. When segregated according to a measure of pipe wall roughness, some semblance of order emerges.

The values of f for data on the so-called "smooth pipe," (made of materials such as glass, lead, copper, brass, i.e., most drawn tubing) fall in a narrow band that is within ±5 per cent of curve B in Fig. 1, which can be expressed by the formula

$$f = 0.00140 + 0.125\, Re^{-0.32} \qquad (4)$$

which was obtained by Drew, Koo, and McAdams[5] from their plot of 1,328 points over the extremely wide Reynolds number range of 3,000 to 3,000,000.

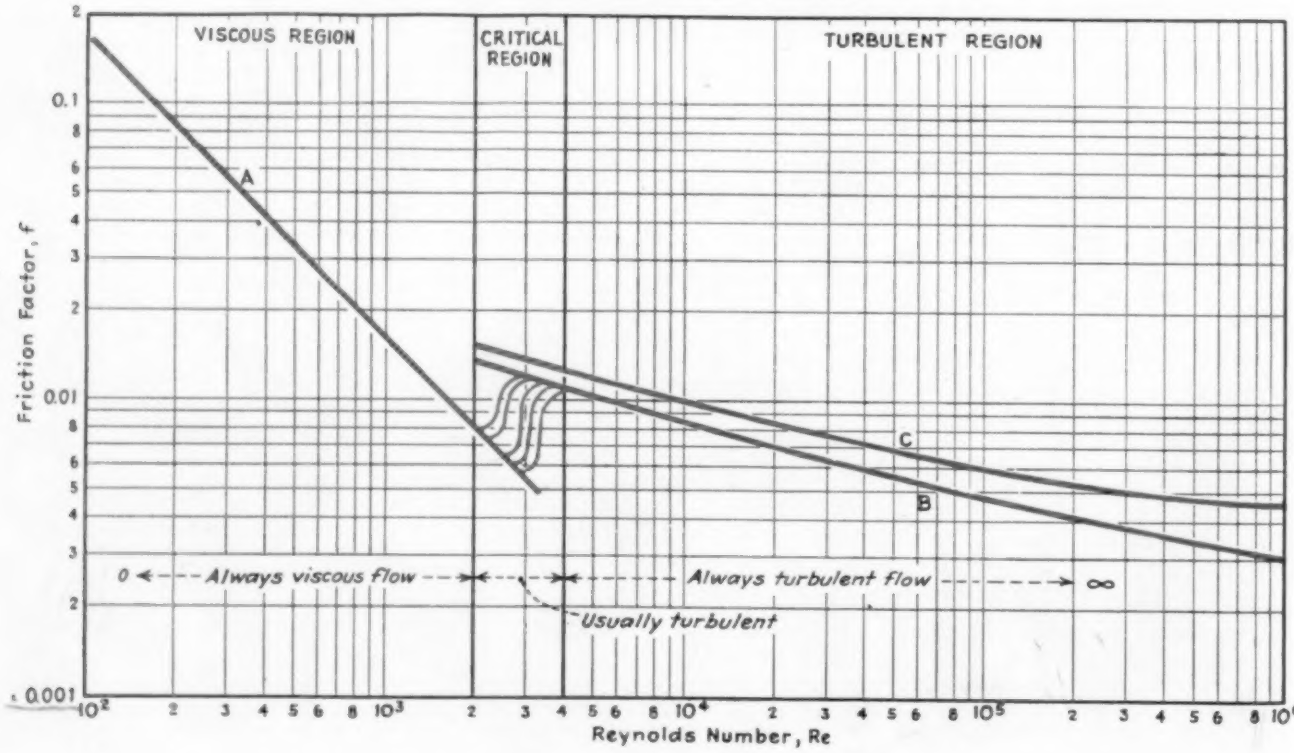
The data on clean "commercial pipe" (iron and steel) lie above those for smooth pipe and form a band that is within ±10 per cent of curve C, Fig. 1, which Drew, Koo, and McAdams expressed by the formula

$$f = 0.00307 + 0.1886\, Re^{-0.38} \qquad (5)$$

Essentially the same data on commercial pipe were analyzed by Pigott[13] and Kemler[7]. They segregated the friction factor *vs.* Reynolds number data into several pipe diameter groups and plotted them separately. After weighting the points on the separate plots and selecting mean curves for each, they assembled them on one sheet and found they had a family of curves in general similar to curves B and C, Fig. 1. The top curve was for the smallest diameters, the others ranging down toward the largest diameters. Their analysis indicated that small pipes are relatively more rough than large pipes. The data used, however, are from many investigators during a long period of time, and the pipes being compared inherently differed in roughness regardless of diameter because they were fabricated under a variety of conditions. Their analysis does not adhere strictly to the requirements of geometric similarity but it does serve as an indication of variation of roughness with pipe diameter. There are reliable data which do not fit into their family of curves.

There are also data on old, tuberculated, corroded, or eroded pipe, and on

Fig. 1—Friction factor curves for viscous and turbulent regions; Curve (B) is average for "smooth pipe," Curve (C) averages data for "commercial pipe"



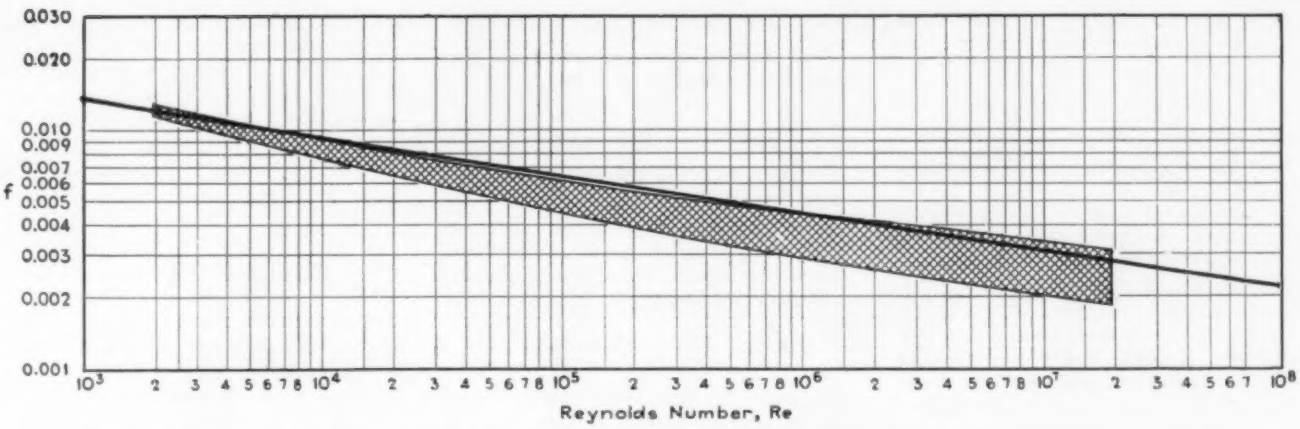


Fig. 2—Straight-line friction factor plot which gives "safe-side" results with commercial pipe, superposed on a data band bounded by Curves (B) and (C) of Fig. 1

artificially roughened pipe. The friction factor curves obtained from these data lie in general above those for "commercial pipe".

The problem which now arises is: What friction factor data are we to use in our calculations of pressure drop, pipe diameter, flow rate, etc.? Obviously, we should be guided by the problem, the kind of pipe, the accuracy required, and the time available for obtaining the desired results. The most accurate method is to use data obtained on the kind of pipe and the diameters to be used. Such data are rarely available; pipe manufacturers have an excellent opportunity to assist in this by collaborating on a program of properly directed research. Our present alternative is to select the data which most nearly approach the conditions involved.

Let us advance first to the methods of calculation with which these friction factors are used and then discuss their selection. Consistent units will be used, e.g., all terms will have the units of feet, pounds, seconds. Later the equations will be stated in units more commonly in use by American engineers.

The fundamental equation for pressure drop due to friction is that derived[6] from Bernoulli's Theorem. The following form is generally called the Fanning Equation:

$$\Delta P = \frac{4fL\rho V^2}{2gD} \qquad (6)$$

When this equation is solved for f, the friction factor, we obtain:

$$f = \frac{2gD\,\Delta P}{4L\rho V^2} \qquad (1)$$

which is identical with Equation (1), which was the form used to determine f from actual data, and then plotted against the Reynolds number. To determine the friction loss in any pipe, the Reynolds number is calculated according to the equation:

$$Re = \frac{DV\rho}{\mu} = \frac{DG}{\mu} \qquad (7)$$

and the value of f corresponding to it is selected from the friction factor plot and substituted in Equation (6). This method permits the selection of whatever friction factor curve best fits the kind and roughness of pipe, regardless of the flow region involved.

Since kind and roughness of pipe are not involved in the viscous region, i.e., a single friction factor curve suffices, that curve can be expressed mathematically as

$$f = 16\,\mu/DV\rho \qquad (3)$$

and substituted in Equation (6) to obtain

$$\Delta P = \frac{32\,\mu LV}{gD^2} \qquad (2)$$

as stated above. This equation can then

TABLE I—NOMENCLATURE

A_1	= area, upstream	Δp_c	= pressure drop due to contraction
A_2	= area, downstream	Δp_e	= pressure drop due to expansion
a	= amortization (fractional, *i.e.* 0.10 for 10 per cent)	Δp_k	= pressure drop due to high pressure or temperature change
b	= maintenance, fractional	p_1	= inlet pressure, lb./sq. in.
C	= cost expression	p_2	= outlet pressure, lb./sq. in.
$C_{p.}$	= annual cost of pipe, dollars	p_{av}	= arithmetic mean pressure, lb./sq. in.
$C_{p.d.}$	= annual cost of pressure drop, dollars	Q	= thousands of cu.ft./hr.
D	= diameter, feet	Re	= Reynolds number, dimensionless
D_i	= diameter, inches	r	= hydraulic radius, feet
E	= overall efficiency, pump and motor, fractional	r_i	= hydraulic radius, inches
F	= factor for fittings and erection	T	= absolute temperature, °K.
f	= friction factor, dimensionless	T_1	= absolute temperature, °K, at inlet
G	= mass velocity, lb./(sec.) (sq. ft.) = $V\rho$	T_2	= absolute temperature, °K, at outlet
g	= acceleration due to gravity, ft./sec.²	T_{av}	= absolute temperature, °K, arithmetic mean
K	= factor in contraction loss	V	= velocity, ft./sec. (i.e., average over the cross-section)
K	= cost of electrical energy, dollars per kw.hr.	X, Y	= coordinates for grid, Fig. 3
L	= length, feet	X	= cost of 1 in. pipe per ft. length, dollars
L_e	= length, feet, equivalent to fittings, etc.	Y	= hours of operation per year
M	= mass velocity, thousands of lb./(hr.) (sq. ft.)	Z	= viscosity, centipoises
m	= weight rate of flow, thousands of lb./hr.	μ	= viscosity, lb./ft.sec. $= Z/1{,}488$
$m.w.$	= molecular weight.	μ_a	= viscosity, lb./ft.sec., at the main body temperature
n	= slope of pipe cost curve	μ_w	= viscosity, lb./ft.sec., at the tube wall temperature
P	= pressure, absolute, in atmospheres	ρ	= density, lb./cu.ft.
ΔP	= pressure drop, lb./sq. ft.		
Δp	= pressure drop, lb./sq. in.		

be transposed into any desired form, e.g., to solve for velocity:

$$V = \frac{gD^2 \Delta P}{32 \mu L} \quad (8)$$

In the turbulent region, however, the conditions are not so simple. Many friction factor curves exist, due to roughness. As stated above, we can use Equation (6) and the most adequate friction factor curve. But when calculating pipe diameter, with known values of rate of flow, fluid density and viscosity, and pipe length, the Reynolds number cannot be calculated, and hence the friction factor cannot be determined. If the friction factor chart is to be used in these cases, the problem must be solved by trial and error, i.e., solving several times by assuming values of diameter until the correct answer is obtained. This same condition exists when solving for rate of flow. When strict accuracy is required, this is the most adequate method. However, in view of the conclusion drawn in the introduction that "There is more to be gained by being on the economical and 'safe side' than to strive for great accuracy," and because most of the pipe selected for plant installation falls in the "commercial pipe" class, use of friction factors on the "safe side" of the band of commercial pipe data will give adequate accuracy for the usual design problem.

In Fig. 2, the shaded area indicates the band of data on commercial pipe as plotted by Drew, Koo, and McAdams[3] and many more points[4] extending the Reynolds number range up to about 20,000,000. The points are for pipe diameters ranging up to 14 ft. in diameter. It is possible to express the mean curve, or the upper border curve, by an equation for f in terms of Re similar to Equation (5), i.e., in a mathematical expression of additive terms. Substitution of this expression in the Fanning Equation (6) would result in a cumbersome equation.

However, a simpler method is to express the data by an equation of a straight line in the same mathematical form as Equation (3). Substitution of this expression in the Fanning Equation would result in a single equation for all fluids in turbulent flow in commercial pipe. Error enters in fitting such a straight line to the shaded area, but in view of the simplicity of the resulting equation, and the retention of economic conditions in being on the "safe side", the following line was selected:

$$f = 0.04\,Re^{-0.16} = 0.04\,(\mu/D V\rho)^{0.16} \quad (9)$$

and its position relative to the shaded area is shown on Fig. 2. (For the actual fitting of this line to the data, see Genereaux[6].) Substitution of this equation for the friction factor line in the Fanning Equation gives

$$\Delta P = 0.00249 L \mu^{0.16} \rho^{0.84} V^{1.84}/D^{1.16} \quad (10)$$

which can be rearranged to solve for any of the variables involved.

Summary of Equations

Equation (2) is for the *viscous region*. It is stated in consistent units, any set such as ft., lb., sec. (or cm., gm., sec.) can be used. In certain commonly used (but not consistent) units, the equation is

$$\Delta p = 0.034 LZm/\rho D_i^4 = \text{lb. per sq. in.} \quad (11)$$

It is exact for all circular pipe irrespective of wall roughness. It can be seen by inspection that the pressure drop varies directly with the viscosity, pipe length, and weight rate of flow, and inversely as the fourth power of the diameter. It can be used safely up to a Reynolds number of 2,000—in the units stated in Equation (7).

Equation (10) is for the *turbulent region* and is also stated in consistent units. In certain common units, the equation is

$$\Delta p = \frac{0.1325\, L\, Z^{0.16}\, m^{1.84}}{\rho\, D_i^{4.84}} = \text{lb. per sq. in.} \quad (12)$$

It is intended for use in plant design problems when extreme accuracy is not required. The results obtained by its use are on the "safe side" of what might occur in commercial pipe over the entire turbulent region for which data are at present available, i.e., up to $Re = 20{,}000{,}000$. It is valid for all Newtonian fluids in steady flow (constant weight rate). Newtonian fluids are those whose values of shearing stress are directly proportional to the rate of shear. They include all the gases and most of the common liquids. Examples of "liquids" which are non-Newtonian are suspensions and plastic liquids, see Perry[14], page 1271.

Special Cases

In non-isothermal flow of liquids there is a temperature gradient between the tube wall and the main stream of the liquid. It is necessary to use some average temperature in evaluating the viscosity. Sieder and Tate[18] correlated pressure drop data taken under conditions of heating and cooling. The terms used were: μ_a = the viscosity at the main stream temperature, and μ_w = the viscosity at the tube wall temperature. With Reynolds number calculated as DG/μ_a, they suggested the following factors:

Viscous region: Multiply f by 1.1 $(\mu_a/\mu_w)^{0.25}$

Turbulent region: Multiply f by 1.02 $(\mu_a/\mu_w)^{0.14}$

For isothermal flow of gases, the arithmetic mean density is used when the pressure drop does not exceed 10% of the final pressure; see Perry,[9] page 721. When the pressure drop is large and one of the end pressures is unknown, the following equation may be used:

$$p_1^2 - p_2^2 = \frac{518\, T\, L\, f\, m^2}{(m.w.)\, D_i^5} \quad (13)$$

For non-isothermal flow of gases when the pressure drop or temperature change is large, a kinetic energy correction may be made by adding algebraically Δp_k, Equation (14), to the pressure drop calculated by Equation (12) in which average values of density and viscosity were used.

$$\Delta p_k = \frac{0.0042\, G^2\, T_{av}}{(m.w.)\, p_{av}} \times \left(\frac{T_2 - T_1}{T_{av}} + \frac{p_1 - p_2}{p_{av}}\right) = \text{lb. per sq. in.} \quad (14)$$

If Equation (12) were used in problems on "smooth pipe", the calculated pressure drop would be too high. (The error would range from zero at $Re = 3{,}000$ to 50 per cent at $Re = 3{,}000{,}000$.) If it were used in problems on very rough pipe, the resulting pressure drop would probably be too low (pipe may become tuberculated and the actual diameter decreased, or it may become corroded and the actual diameter be increased).

Nomographic Chart for Flow

Equation (12) can be adapted readily to a nomographic chart which affords rapid calculations, and by including density and viscosity data, it can be made independent for solving the majority of problems. The effect of altering the value of any variable can be determined quickly. It also makes unnecessary the solution of fractional exponents which to many engineers are time consuming. Fig. 3 is based on Equation (12). The same type of chart has been published previously.[3,12,6] It has been revised to conform with new friction factor data,[6] and additional points for fluids have been added by the use of a more convenient grid method.

The chart consists essentially of scales for actual inside pipe diameter, D_i; weight rate of flow, m; pressure drop per 100 ft. of pipe length, $100\,\Delta p/L$; and a kinematic viscosity, $Z^{0.16}/\rho$. A scale of mass velocity, M, has been added to permit its determination and provide for using it with D_i or m when m or D_i, respectively, is unknown.

Temperature and molecular weight scales are given in the form of a line-coordinate chart by which values of $Z^{0.16}/\rho$ at atmospheric pressure are determined directly. While it is true that the viscosities of gas mixtures are not

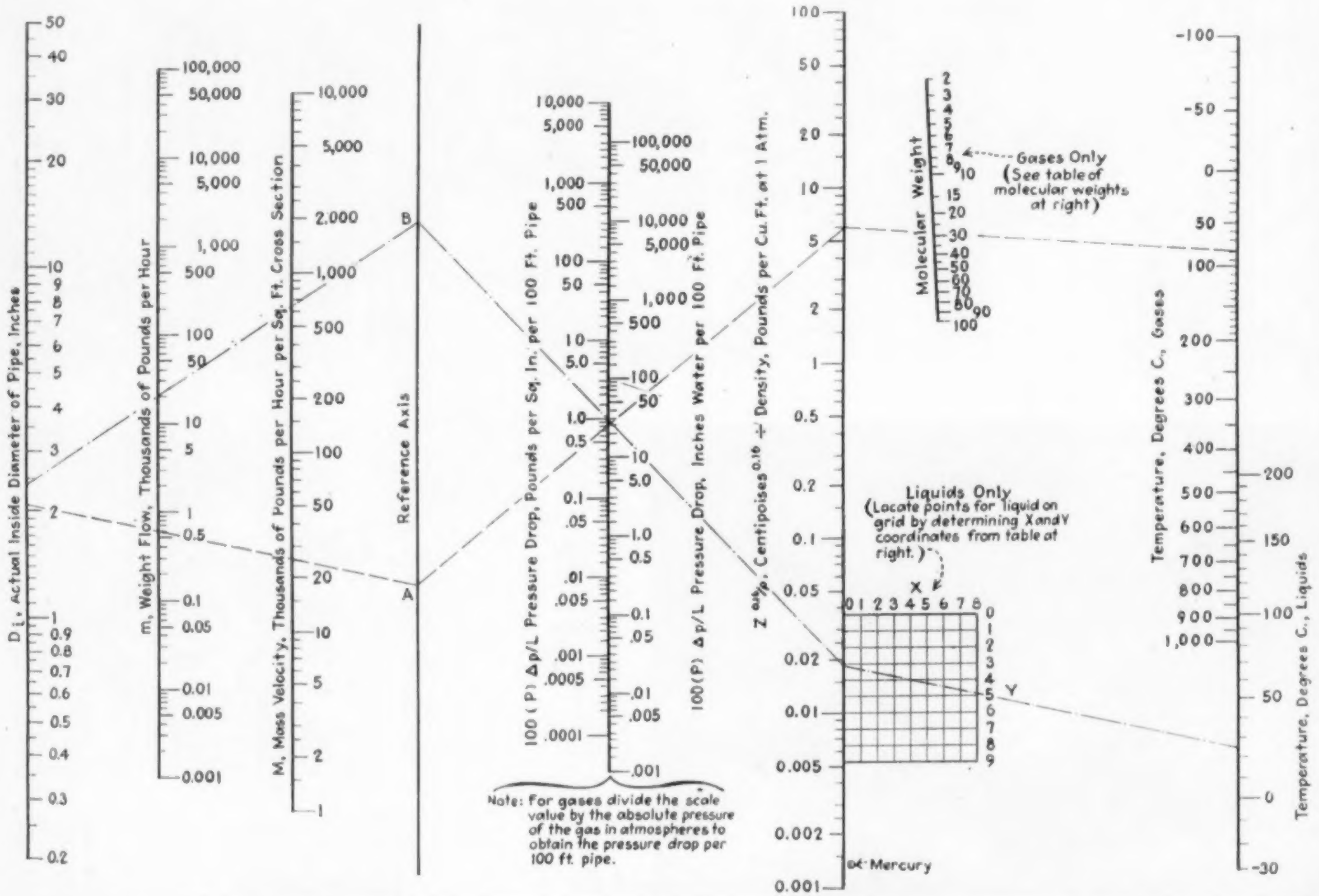


Fig. 3—Pipe Flow Chart for Turbulent Flow (Based on Clean Steel Pipe)

For viscous flow, i.e., for Reynolds numbers less than 2,000, use the Hagen-Poiseuille equation, $\Delta p = 0.034\ L\ Z\ m/(\rho D_i^4)$, where Δp is pressure drop in pounds per square inch, L is pipe length in feet, Z is viscosity in centipoises, m is weight flow in thousands of pounds per hour, ρ is density in pounds per cubic foot and D_i is the actual inside diameter of the pipe in inches.

Use of Chart

Gases—Air at a pressure of 120 lb. ga. and a temperature of 80 deg. C. is flowing at the rate of 600 lb. per hour through a 2-in. standard steel pipe. What is the pressure drop per 100 ft. of pipe? The actual inside diameter of 2-in. pipe is 2.067 in. The pressure of the air is $(120+14.7) \div 14.7 = 9.16$ atm. abs. Connect $D_i = 2.067$ with $m = 0.6$ and extend the line to intersect the reference axis at A. Connect 80 deg. C. on the gas scale with molecular weight 29 and intersect the $Z^{0.16}/\rho$ axis at 6.0. Join this last intersection with point A, intersecting $100\ (P)\Delta p/L$ at 0.82. The drop then is $0.82/9.16 = 0.089$ lb. per sq. in. per 100 ft. of pipe.

Liquids—A 50 per cent solution of glycerol is being pumped through a line at the rate of 20,000 lb. per hour and at a temperature of 25 deg. C. If the allowable pressure drop per 100 ft. of pipe is 1.0 lb. per sq. in., what size of pipe is required? Connect 25 deg. C. on the liquid scale with the intersection of grid values $X = 2.9$, $Y = 3.7$, as shown in the tabulation for 50 per cent glycerol. Extend the line to $Z^{0.16}/\rho = 0.0185$ and connect this point through $100\Delta p/L = 1.0$ to the reference axis at point B. Connect point B through $m = 20$ to $D_i = 2.4$ in., indicating the required size of pipe as 3-in. standard steel (actual inside diameter, 3.07 in.).

Molecular Weights of Gases

Gas	Mol. wt.
Acetylene	26.0
Air	29.0
Ammonia	17.0
Argon	39.9
Bromine	159.8
Butane	58.1
Butylene	56.1
Carbon dioxide	44.0
Carbon monoxide	28.0
Chlorine	70.9
Cyanogen	52.0
Ethane	30.1
Ethylene	28.0
Fluorine	38.0
Helium	4.0
Hydrogen	2.0
Hydrogen bromide	80.9
Hydrogen chloride	36.5
Hydrogen cyanide	27.0
Hydrogen fluoride	20.0
Hydrogen sulphide	34.1
Methane	16.0
Neon	20.2
Nitrogen	28.0
Oxygen	32.0
Pentane	72.1
Propane	44.1
Propylene	42.1
Sulphur dioxide	64.1

Coordinates for Liquids

Liquid	X	Y
Acetic acid, 100%	1.3	4.0
Acetic acid, 70%	1.8	3.7
Acetone	0.2	3.4
Ammonia, anhydrous	1.5	3.8
Aniline	2.5	3.2
Benzene	1.2	3.7
Butanol	2.5	2.5
Calcium chloride brine, 25%	4.0	4.8
Carbon disulphide	0.0	5.7
Carbon tetrachloride	0.8	6.0
Chloroform	0.2	6.1
Dichlorodifluoromethane ("F-12")	0.0	5.5
Diphenyl	1.0	3.5
Ether	0.6	3.5
Ethyl acetate	0.8	4.0
Ethyl alcohol, 95%	1.9	3.1
Ethyl chloride	0.0	4.1
Ethylene glycol	3.3	2.9
Glycerol, 100%	6.4	2.0
Glycerol, 50%	2.9	3.7
Hydrochloric acid, 31.5%	1.1	4.2
Linseed oil, raw	3.4	1.5
Mercury	see chart	
Methyl alcohol, 100%	0.6	3.2
Nitric acid, 95%	1.0	5.7
Nitric acid, 60%	1.8	4.9
Nitrobenzene	1.7	4.3
Octane	0.7	2.8
Phenol	3.2	3.3
Sulphur dioxide	0.5	6.2
Sulphuric acid, 111%	3.0	4.5
Sulphuric acid, 98%	3.2	4.7
Sulphuric acid, 78%	3.4	4.5
Tetrachlorethylene	0.4	6.2
Toluene	3.3	4.7
Turpentine	1.8	3.3
Water	2.3	4.2

exactly proportional to the molecular weight, the error is small when the 0.16 power of the viscosity is used.

For liquids, a separate temperature scale and a table of certain liquids with coordinate points for locating their positions on the grid are given. The grid system is used because the points for the data would be compacted into too small a space for clarity. The coordinates for locating points for liquids not listed in the table may be located as follows. Values of $Z^{0.16}/\rho$ for two temperatures are calculated and the corresponding values connected by straight lines. The intersection locates the point. For example, in locating the point for 95 per cent ethyl alcohol:

Temperature Deg. C.	0	70
Viscosity, centipoises, Z	1.798	0.504
$Z^{0.16}$	1.099	0.896
Density, lb./cu.ft.,ρ	51.2	47.8
$Z^{0.16}/\rho$	0.0215	0.0188

By connecting 0 deg. C. with 0.0215 and 70 deg. C. with 0.0188, the grid coordinates $X = 1.9$ and $Y = 3.1$ are obtained.

Two examples of calculations on the chart follow:

Use of Chart

Gases—Air at a pressure of 120 lb. ga. and a temperature of 80 deg. C. is flowing at the rate of 600 lb. per hour through a 2-in. standard steel pipe. What is the pressure drop per 100 ft. of pipe? The actual inside diameter of 2-in. pipe is 2.067 in. The pressure of the air is $(120 + 14.7)/14.7 = 9.16$ atm. abs. Connect $D_i = 2.067$ with $m = 0.6$ and extend the line to intersect the reference axis at A. Connect 80 deg. C. with molecular weight 29 and intersect the $Z^{0.16}/\rho$ axis at 6.0. Join this last intersection with point A, intersecting $100(P)\Delta p/L$ at 0.82. The drop then is $0.82/9.16 = 0.089$ lb. per sq. in. per 100 ft. of pipe.

Liquids—A 50 per cent solution of glycerol is being pumped through a line at the rate of 20,000 lb. per hour and at a temperature of 25 deg. C. If the allowable pressure drop per 100 ft. of pipe is 1.0 lb. per sq. in., what size of pipe is required? Connect 25 deg. C. on the liquid scale with the intersection of grid values $X = 2.9$, $Y = 3.7$, as shown in the tabulation for 50 per cent glycerol. Extend the line to kinematic viscosity value 0.0185. Connect this point through $100\Delta p/L=1.0$ to the reference axis at point B. Connect point B through $m = 20$ to $D_i = 2.4$ in., indicating the required size of pipe as 3-in. standard steel (actual inside diameter, 3.07 in.).

Choosing Pipe Diameter for Economy

It has previously been mentioned that the selection of pipe should be made on an economical basis so that the total annual cost of owning and operating the fluid handling system will be a minimum.

The method to be used in arriving at the most economical pipe size will be clear from a consideration of the factors entering into this total cost. The initial cost of the pipe and fittings is directly proportional to the diameter, as are the other factors of pipe operating cost, depreciation and maintenance, which are a constant percentage of initial pipeline cost. The cost of pressure drop (cost of pumping or blowing), however, is inversely proportional to the diameter, so that a balance can be struck at a diameter which will give the minimum sum for these two costs.

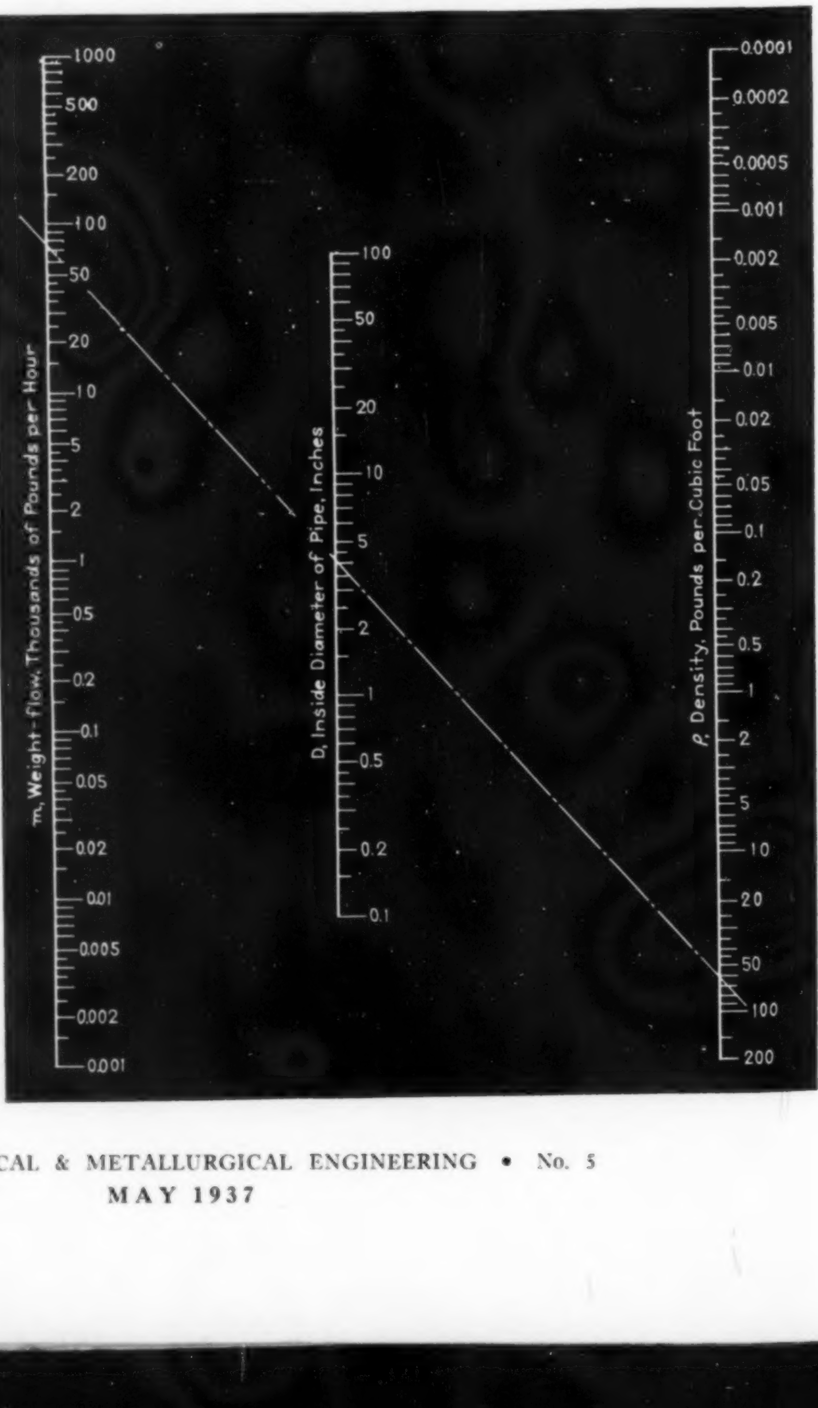
The cost of pipe can be expressed approximately in terms of that of 1-in. pipe, multiplied by the actual diameter raised to a power, or XD_i^n. For steel pipe, the slope of the cost curve is essentially $n = 1.5$, and the equation, therefore, $XD_i^{1.5}$. The total annual cost of pipe may be expressed as follows:

$$C_p = (a+b)\ (F+1)\ XD_i^n \qquad (15)$$

where cost is the total of depreciation and maintenance on a pipe line costing initially XD_i^n for the pipe, plus $F \times D_i^n$ for fittings, valves, erection, etc.

The second item in total annual cost, the cost of pressure drop, is taken as zero when it is not charged to operation, as in drawing water from a main. When pumping of liquids or compressing of gases is required, that cost must be included. In the case of liquids, the volume of flow multiplied by the pressure drop expresses exactly the work done, but for gases, this is not exact. Assuming it to be true introduces a percentage error equal to about

Fig. 4—Economical pipe diameter chart, based on simplified Equation (19) in text; connect weight flow and fluid density to obtain economical inside diameter of pipe



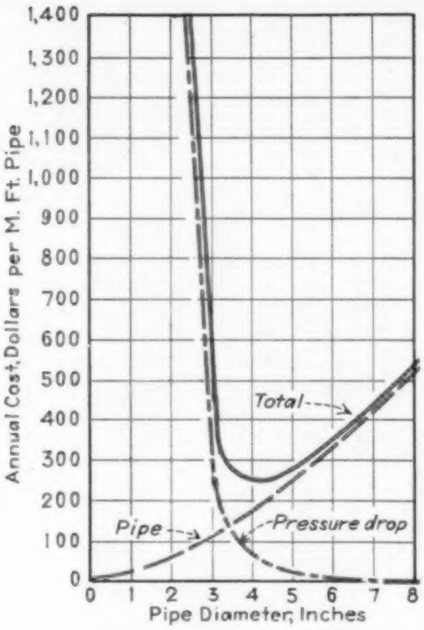


Fig. 5—Example illustrating interrelations of cost of pipe, cost of pumping and total cost in the case where water at 20 deg. C. is being pumped at the rate of 75,000 lb. per hour

half the percentage pressure drop, an error which is unimportant for small pressure drops. Hence this approximation will be made. (This method cannot, of course, apply to steam, since the value of the pressure lost in a steam line depends on the temperature and pressure level.)

Cost of Pressure Drop

Assuming, then, that the cost of pressure drop is proportional to the product of flow volume and pressure drop, the hourly energy consumption is $1{,}000(m/\rho)(144\Delta p)$ ft. lb. or $1{,}000m(144\Delta p)/(2{,}654{,}200E\rho)$ kw.-hr. In dollars per year this cost becomes $0.0542m\Delta pYK/(E\rho)$, or substituting for Δp its value from Equation (12), the annual dollar cost of pressure drop per foot of pipe becomes:

$$C_{p.d.} = \frac{0.0072\, m^{2.84} Z^{0.16}\, YK}{D_i^{4.84} \rho^2 E} \qquad (16)$$

The total annual dollar cost of pipe plus pressure drop is $C = C_p. + C_{p.d.}$, which expression is differentiated with respect to the diameter and the differential set equal to zero to determine minimum cost. The resulting equation is:

$$D_i^{4.84+n} = \frac{0.0348\, m^{2.84} Z^{0.16}\, YK}{n(a+b)\,(F+1)\, XE\rho^2} \qquad (17)$$

which is a general expression for any kind of pipe. Substituting for n its value of 1.5 for steel pipe and solving for D_i the equation becomes:

$$D_i = \frac{m^{0.448} Z^{0.025}}{\rho^{0.315}} \times \left[\frac{0.0232\, YK}{(a+b)\,(F+1)\, XE}\right]^{0.158} \qquad (18)$$

In order to simplify still farther, the "fixed cost" expression within the brackets was evaluated for extreme and normal values, and an average figure of 2.2 taken. Since $Z^{0.025}$ is nearly unity for most viscosity values, another simplification is to neglect it, giving as the final simplified expression:

$$D_i = 2.2\, m^{0.448}/\rho^{0.315} \qquad (19)$$

Although for most accurate results it may be desirable to use Equation (17), Equation (19) is adequate for ordinary plant conditions, for fluids having viscosities lying between 0.02 and 30 centipoises.

The alignment chart, Fig. 4, has been constructed for its ready solution. In using the chart, select the next standard size of pipe above the actual diameter determined. To do so is to be on the "safe side" and will prove most economical.

The following example illustrates the relation between pipe diameter and total annual cost of pipe and pressure drop. The costs of pipe and of pressure drop for conveying water at 20 deg. C. at the rate of 75,000 lb. per hr. (150 gal. per min.) for 1,000 ft. were calculated for actual pipe sizes of 1 to 8 in. The results are given graphically in Fig. 5, and indicate a 4-in. pipe as the most economical. It is also indicated that the total annual cost of 6-in. pipe is practically identical with that for 3-in. pipe. Note that Fig. 4 gives exactly the same result, namely a 4-in. pipe, taking ρ at 62.5 lb. per cu.ft.

Miscellaneous Pipe-Line Losses

Expansion and Contraction Losses—When the cross-sectional area is *suddenly enlarged* the velocity head decreases, and if there were no friction losses the static head would increase a corresponding amount. However, a part of the head is lost due to friction. When the cross-sectional area is *suddenly reduced* there is a similar loss of pressure. These losses may be calculated by means of the equations shown in Table II in which Δp_e = expansion loss, lb. per sq.in. and Δp_c = contraction loss, in lb. per sq. in.

Pipe Fittings and Valves—In calculating fluid flow problems on piping systems in which elbows, bends, tees, valves, etc., occur, it is convenient to add to the pipe length, L, the equivalent length of pipe, L_e, which would give the same pressure drop. The values given in the second part of Table II are in terms of the number of diameters of pipe length. For example, if a 90 deg. elbow in a 3-in. line is equivalent to 40 diameters, then the equivalent length of straight 3-in. pipe is $40(3/12) = 10$ ft.

Flow in Uniform Non-Circular Conduits

The friction factor has been found to be a function of the Reynolds number for flow in pipes and ducts of all cross-

Table II — Miscellaneous Losses in Pipe Lines

Equations for Expansion and Contraction Losses

$$\Delta p_e = \frac{\rho(V_1 - V_2)^2}{2g \times 144} = \frac{0.279\, m^2}{\rho}\left(\frac{1}{D_1^2} - \frac{1}{D_2^2}\right)^2 \qquad (20)$$

$$\Delta p_c = \frac{K\rho V_2^2}{2g \times 144} = \frac{0.279\, m^2}{\rho}\left(\frac{1}{D_2^2}\right)^2 K \qquad (21)$$

$$K = 0.4\left(1.25 - \frac{A_2}{A_1}\right) = 0.4\left(1.25 - \frac{D_2^2}{D_1^2}\right) \text{ when } \frac{A_2}{A_1} < 0.715$$

$$K = 0.75\left(1 - \frac{A_2}{A_1}\right) = 0.75\left(1 - \frac{D_2^2}{D_1^2}\right) \text{ when } \frac{A_2}{A_1} > 0.715$$

Losses in Fittings and Valves

(Turbulent Flow Only)

	Pipe diameters		Pipe diameters
90 deg. elbows, ⅜–2½ in. ...	30	Tee when fluid enters branch	90
3–6 in. ...	40	Square elbow (intersection of two cylinders)	50
7–10 in. ...	50	Return bend, made of two elbows, use twice the value for one 90 deg. elbow.	
45 deg. elbows, 1–3 in. ...	15	Gate valves, open..........	10
4–10 in. ...	20	Globe valves, open.........	100–300
90 deg. long radius elbows ...	15–20		
Tee used as elbow	60		

For further descriptions, see [13] and [2].

Table III—Hydraulic Radius for Various Sections

Pipes and Ducts Running Full	Hydraulic Radius
Circle, diam. = D	$D/4$
Annulus, inner diam. = d, outer diam. = D	$(D-d)/4$
Square, side = D	$D/4$
Rectangle, sides a, b	$ab/2\ (a+b)$

sectional shapes so far examined. The form of Reynolds number used is

$$Re = 4\,r\,V\,\rho/\mu = 4\,r\,G/\mu \qquad (22)$$

The hydraulic radius r = area of stream cross-section divided by wetted perimeter. For a circle, $r = D/4$ or $D = 4r$. Substitution of D for $4r$ in Equation (22) results in the Reynolds number for circular pipe as given previously in Equation (7):

$$Re = D\,V\,\rho/\mu = D\,G/\mu \qquad (7)$$

The velocity V in Equation (22) is that calculated from the actual area of the duct, for example,

$$V\,\rho = G \qquad (23)$$

where G is the mass velocity, lb. per sec. per sq.ft., or the weight rate of flow divided by the actual area of the duct.

The friction factor for non-circular ducts is the same as that for circular pipe, Equation (1), with $4r$ substituted for D:

$$f = 2gr\,\Delta P/L\rho V^2 = 2gr\rho\,\Delta P/LG^2 \qquad (24)$$

The general form of the Fanning Equation is obtained by transposing Equation (24) or by substituting $4r$ for D in Equation (6):

$$\Delta\,P = fL\,\rho\,V^2/2gr = fLG^2/2g\,\rho\,r \qquad (25)$$

By referring to Fig. 6, it can be seen from the positions of the viscous region lines for rectangular ducts of various aspect ratios (length/breadth) that each duct shape has a different line. The ones illustrated are taken from Davies & White[3] who also give values for ellipses and the equilateral triangle. They stated, after analyzing the available data, that the friction factor in the turbulent region is independent of the form of the cross-section, for all practical purposes. The curves B and C from Fig. 1 are therefore shown on Fig. 6 for turbulent flow. From this, it can be assumed that the straight line selected for circular pipe, Equation (9), is equally applicable to non-circular conduits. In terms of the hydraulic radius, it is stated as:

$$f = 0.032\,(\mu/r\,V\rho)^{0.16} = 0.032\,(\mu/rG)^{0.16} \qquad (26)$$

and when substituted in Equation (25):

$$\Delta P = 0.000498\,L\,\mu^{0.16}\,\rho^{0.84}\,V^{1.84}/r^{1.16} \qquad (27)$$

Equations (22) to (27) are in consistent units. Equation (27) expressed in more commonly used units is:

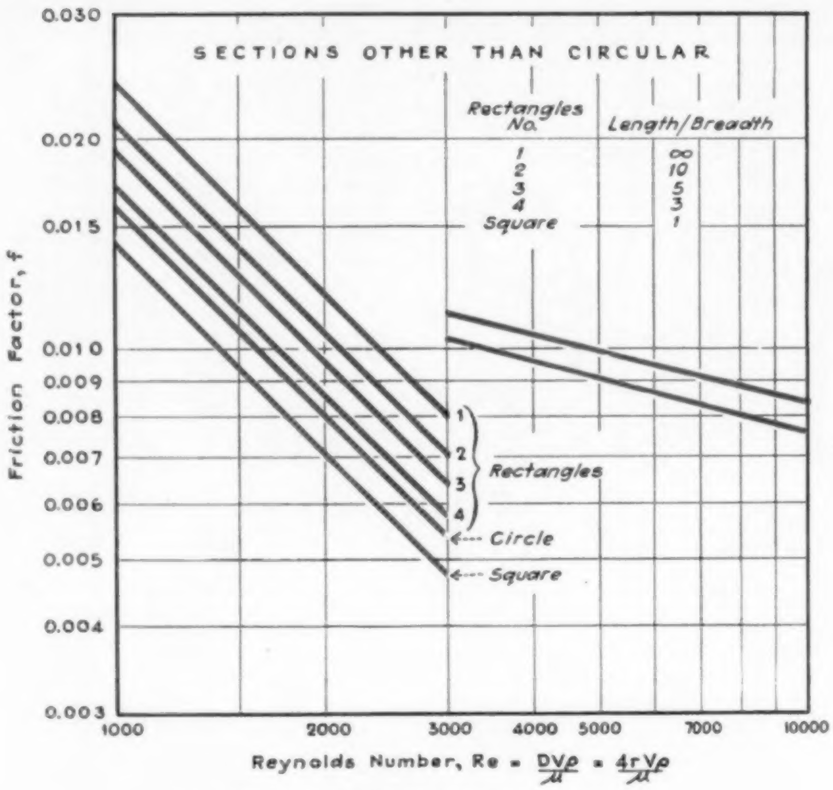


Fig. 6—Friction factor plots for non-circular ducts

$$\Delta p = 0.000019\,LZ^{0.16}\,\rho^{0.84}\,V^{1.84}/r_i^{1.16} \qquad (28)$$

Values of the hydraulic radius r for various cross-sections are given in Table III. Others may be found in Perry[10].

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Safety in Handling Fluids

A Selected Bibliography

NECESSITY for safety in the storing and conveying of fluids is vital to the preservation of man power and to economical plant operation. Publications of various trade associations and regulatory bodies contain much valuable material on safety—material such as safe construction codes, safety rules for personnel, and safe operating procedures. The following list of such publications does not pretend to be complete, but it does contain most of the more important material that is readily available.

Construction and Repair of Containers

"A.S.M.E. Boiler Construction Code"—available in various sections from the American Society of Mechanical Engineers, 29 West 39th St., New York.

Of chief interest are rules for the safe construction of unfired pressure vessels.

"A.P.I.—A.S.M.E. Unfired Pressure Vessel Code"—American Society of Mechanical Engineers.

Similar to the Unfired Pressure Vessel Section of the Boiler Construction Code except that the rules are drawn up specifically for the needs of the petroleum industry.

"National Board Rules for Repair of Boilers by Fusion Welding"—the National Bureau of Casualty and Surety Underwriters, 1 Park Ave., New York.

Indicates the extent to which fusion welding is acceptable to the authorities for steam boiler repairs.

"Rules for Fusion Welding of Gravity Tanks, Tank Risers, and Towers"—International Acetylene Association, 30 East 42nd St., New York.

"Specifications on All-Welded Storage Tanks (Tentative), First Edition"—American Petroleum Institute, 50 West 50th St., New York.

Applies to the large above ground bulk storage tanks used by petroleum companies.

"All-Welded Production Tanks (Tentative)"—American Petroleum Institute.

"Cleaning Petroleum Storage Tanks"—American Petroleum Institute.

An accident prevention manual.

"American Welding Society Tentative Recommendations Describing Procedure to be Followed in Preparing for Welding or Cutting Certain Types of Containers Which Have Held Combustibles"—American Welding Society, 29 West 39th St., New York.

Applies principally to containers which cannot be entered for cleaning, i. e., shipping drums, truck tanks, etc.

Interstate Commerce Commission Specifications for shipping containers: i.e., I.C.C. No. 8, for acetylene gas; and I.C.C. No. 3-A, for oxygen and other non-liquefied gases. Published in Bureau of Explosives Pamphlet No. 9, available from The Bureau of Explosives, 30 Vesey St., New York.

Piping and Fittings

"Code for Pressure Piping"—American Standards Association, 29 West 39th Street, New York. Sponsored by American Society of Mechanical Engineers.

Represents a standard of minimum safety requirements for materials, dimensions, design, erection and final tests. Piping covered, steam generating plants, central heating plants, industrial plants, city gas distribution systems, cross-country transportation systems, gas manufacturing plants, gas or air-compressing stations, processing plants, oil refineries, gasoline recovery plants, and district heating systems. Includes important section on fabrication details.

"Scheme for Identification of Piping Systems"—American Standards Association.

"Recommended Practice for the Installation, Maintenance and Use of Piping and Fittings for City Gas"—American Standards Association.

"Identification of Piping Systems"—Safe Practices Pamphlet No. 88, National Safety Council, 20 North Wacker Drive, Chicago, Illinois.

"City Gas—Installation, Maintenance and Use of Piping and Fittings"—standard fire protection regulation published by the National Board of Fire Underwriters. Available from National Fire Protection Association, 60 Battery March St., Boston, Massachusetts.

"Compressed Gas Systems, Other Than Acetylene, for Lighting and Heating"—standard fire protection regulation published by the National Board of Fire Underwriters. Available from National Fire Protection Association.

Storage and Handling of Fluids

"Gas Safety Code"—American Standards Association. Intended for use in the chemical industry.

"Safe Handling and Use of Compressed Gas Cylinders"—Compressed Gas Manufacturers Association, Inc., 120 West 42d Street, New York.

Deals with cylinders for oxygen, acetylene, combustible gases, carbonic gas, sulphur dioxide, chlorine and anhydrous ammonia.

"Industrial Poisons and Dangerous Substances"—United States Navy Yards and Naval Stations, Section 4 of General Safety Rules. Available from Superintendent of Documents, Washington.

Safe Practice Pamphlets available from National Safety Council: "Safe Practices in Handling Compressed Gases," No. 95; "Handling, Cleaning and Filling Drums and Barrels," PET.-8; "Safe Practices in Loading Tank Cars," PET-3; "Pipe Lines and Tanks as Causes of Accidents," CHEM.-1; "Storage Tanks for Oils, Acids and Dry Materials," No. 63 and "Acids and Caustics," No. 25.

Fire Protection

"Fire Hazard Properties of Certain Flammable Liquids, Gases and Volatile Solids"—National Fire Protection Association.

"Marine Fire Hazards"—National Fire Protection Association. Contains appendixes reprinted separately: A—Freeing Oil Tanks of Explosive or Toxic Gases. B—Stowage of Hazardous Commodities.

This last appendix contains an extensive list of gases and liquids classified as to stowage hazard.

"Oil Burning Equipment, and the Storage and Use of Oil Fuels in Connection Therewith"—standard fire protection regulation published by the National Board of Fire Underwriters. Available from National Fire Protection Association.

"Gas Systems for Welding and Cutting"—standard fire protection regulation published by the National Board of Fire Underwriters. Available from National Fire Protection Association.

Contains regulations applying to acetylene generators, service piping systems for acetylene and oxygen, cylinder manifolds, storage of cylinders, calcium carbide and welding equipment, and general precautions.

Safe practice pamphlets available from National Safety Council: "Gas and Electric Welding," No. 23; and "Fire Causes and Prevention," No. 31.

"Welding Codes and Specifications"—International Acetylene Association.

A discussion of various safe construction codes and specifications relating to welding.

Pipe Friction Note

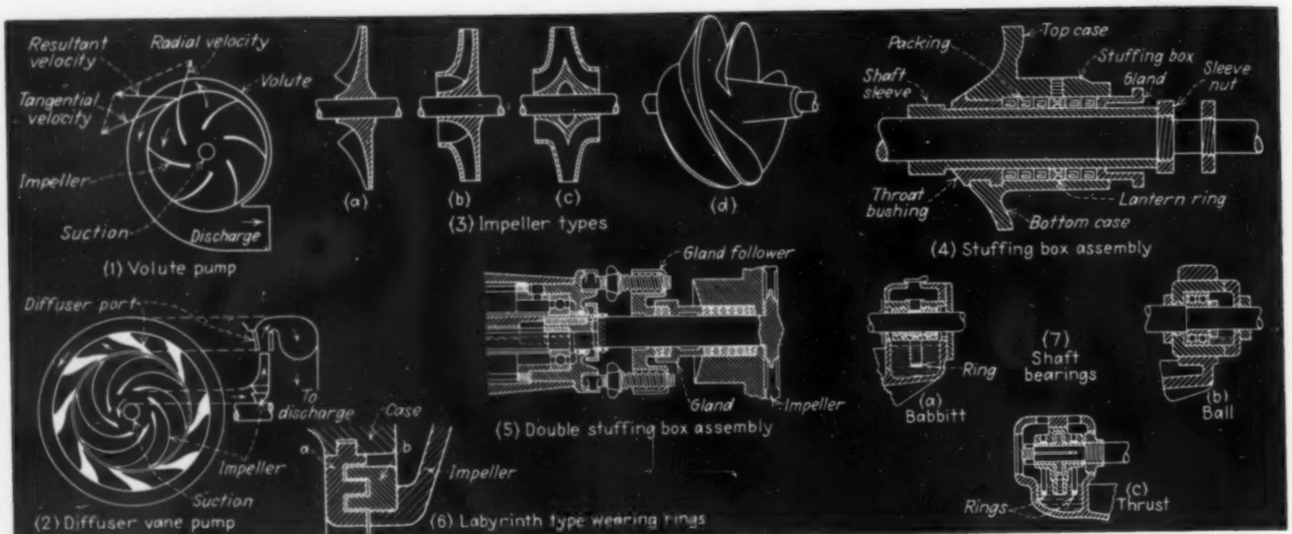
Mr. Ed S. Smith, Jr., the author of our Fluid Measurement and Control paper which appears on page 278, prepared the following short note to explain a situation in hydraulics which seems generally to have been taken for granted. Although it was originally a part of the aforementioned manuscript, its use seems more appropriate in the present location. —Editor.

IN 1738 the Swiss, Daniel Bernoulli, announced that the principle of conservation of energy applied where a fluid of head H ft. accelerated a portion of itself through an orifice or short nozzle, to reach a velocity of V ft. per sec. His relation may be rewritten as $V = C\sqrt{2gH}$ or $H = kV^2/2g$, where g is the acceleration of gravity and C is an empirical constant $= \sqrt{1/k}$. When engineers wanted to compute the friction loss in a long pipe, not unnaturally they assumed that a similar relation held and they set H equal to $f(L/D)(V^2/2g)$, where f is the friction factor (another empirical constant), and L/D is the length of the pipe expressed in diameters. This relation, the Fanning or Darcy equation, is so hallowed by tradition that it may seem presumptious even to question its legitimacy. Yet why should the friction loss vary as the square of the velocity? This is no longer a case of accelerating flow through a hole in the wall of a reservoir.

It happens, however, that there is a parallel between the situation in turbulent flow such as we have been discussing, and in viscous flow, and that this parallel justifies the Fanning equation. Poiseuille, the French physician who investigated the action of the heart in pumping blood several generations ago, found that in the case of the viscous streamline flow of blood at low velocities in the small veins $\Delta P = 32\mu LV/gD^2$ where ΔP = the pressure drop in pounds per sq. ft. and μ = the viscosity in lb./(ft. sec.) units. This absolute viscosity μ results from an interchange of momentum on a molecular scale between adjacent streamlines.

Now with turbulent flow there is a corresponding mechanical viscosity μ_m which results from the interchange of momentum by eddies, on a macroscopic scale, between adjacent "dynamic" streamlines. Such momentum must increase directly with the density ρ (pounds per cu. ft.), the velocity V, and the diameter D. That is, $\mu_m = k'\rho VD$. Hence, substituting in the Poiseuille equation the conditions for turbulent flow we obtain $\Delta P = 32(k'\rho V)/gD^2 = 64\ k'\rho(L/D)(V^2/2g)$. But, where H is the loss in head due to friction, in feet of the fluid flowing, and is equal to $\Delta P/\rho$, $H = 64\ k'(L/D)(V^2/2g)$, or $H = f(L/D)(V^2/2g)$ which is the equation first assumed to hold for turbulent flow.

That is, in turbulent flow the head loss increases both with the velocity and with the mechanical viscosity, the latter itself increasing with the velocity. The result is dependence on the square of the velocity. Thus it is seen that the true reason for the square relation in turbulent flow is the effect of velocity on mechanical viscosity. But since turbulence at ordinary flow rates is not complete, the eddies are interfered with by the walls, and f is not a constant but varies with the Reynolds number.



These parts and assemblies are common to a number of centrifugal pumps

PUMPS AND PUMPING

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A PROMINENT pump engineer once wrote that the design of centrifugal pumps is about ten per cent theory and ninety per cent experience. In other words, the marked advances that have been made in improved performance and construction of pumps during the past fifteen or twenty years have not been because of any particularly new discoveries in the field of pure hydraulics, but have come through the knowledge gained from experience with various types of pumps in actual operation.

With equal force it might be stated now that the selection of the proper pump for any particular service is almost entirely a matter of experience. All too frequently the selection of pumps in the chemical and process industries has been on a more or less trial and error basis. Thus we find old type pumps still operating in many plants when the latest data available would indicate that for efficient operation they should be replaced with pumps of a different type.

In order that the engineer in the chemical plant may be in a better position to analyze his pumping equipment and requirements, the various available pump types are set forth here along with their advantages and disadvantages for different uses. Limited space makes it impossible to cover the entire field, but by presenting a number of the general types, a broad foundation is offered for further investigation in connection with individual pumping requirements.

A general classification of pumps used in the chemical field is shown in the following table. A more detailed classification can be found in the "Standards of the Hydraulic Institute."

Classification of Pumps

A. Centrifugal
- 1. Standard types
  - a. volute
    - (1) single stage
    - (2) multistage
  - b. diffuser
    - (1) single stage
    - (2) multistage
- 2. Peripheral turbine
- 3. Screw impellers
- 4. Propeller types

B. Rotary
- 1. Gear types
- 2. Screw types
- 3. Vane types
- 4. Cam types

C. Reciprocating
- 1. Power types
  - a. simplex
  - b. duplex
  - c. triplex
- 2. Steam pumps
  - a. simplex
  - b. duplex

D. Deep well
- 1. Turbine
- 2. Reciprocating

E. Special types
- 1. Air lift
- 2. Miscellaneous air types

If it were possible to set aside each type of pump as belonging to a particular field, the problem of proper selection would be a fairly simple one. However, the fields of application overlap, and in many cases the final selection may be only a matter of individual preference on the part of the engineer who does the selecting. Where steam is available, and the exhaust steam can be used for heating or processing, steam pumps can be used in many cases where the selection would otherwise be a centrifugal or rotary pump. Centrifugal pumps have such a large field of application that they can be used for almost any service. Rotary pumps are used principally for handling viscous liquids, but they are also applicable in many instances where small capacities against high pressures are desired. Thus, it will be seen that the various types of pumps are more or less in competition with each other, and the engineer making a selection for his own particular requirement will do well to investigate all of the types available.

Centrifugal pumps are probably the most widely used today, chiefly because of their simple construction, their adaptation to standard motor speeds or efficient turbine speeds, and their lower cost of maintenance. An important feature of these pumps is that the discharge is smooth and continuous and free from any shocks or pulsations. Furthermore, the discharge valve may be shut off without building up any dangerous pressures or causing any increase in the horsepower required. Compared to the reciprocating pump, the centrifugal pump is much lighter and does not require as heavy a foundation or occupy as much space.

Where the centrifugal pump can be installed with the liquid flowing to the pump, it would usually be preferred to other types on account of the probable lower cost, simpler construction, and greater adaptability for use with different materials. The principal difficulty with the use of centrifugal pumps is that they are not normally self-priming, and where the material does not flow to the pump, facilities must be provided for priming. In certain sizes, however, and in certain styles, self-priming centrifugal pumps can be obtained and many of these are in use in the chemical industries.

A centrifugal pump is a device for increasing the velocity head of a liquid by the action of centrifugal force, after which, by an increase in the cross-section of the flow passage, the greater

part of this added velocity head is converted to pressure head, thus causing flow. All centrifugal pumps, therefore, contain a rotating part called a runner or impeller, mounted on a shaft and rotating on bearings within a casing in which the added velocity head is converted to pressure head. The most common casing is the volute type, a progressively expanding annular casing surrounding the impeller periphery. Fig. 1 illustrates this type of casing and shows by means of velocity vectors that the resultant direction of flow of liquid leaving the impeller is such that a certain amount of turbulence exists owing to the change of direction and cross-section. In cases where the highest efficiency is necessary and the more costly construction can be justified, a type of casing which more completely converts the added velocity head to pressure head is available. This type, Fig. 2, is known as the diffuser vane type and is sometimes referred to as a turbine pump, since the construction is similar to a hydraulic turbine. Another type of centrifugal pump, which will be described later, is also called a turbine pump, but differs materially in principle from the type of Fig. 2. In the stationary diffuser section of the pump just described, the direction of flow is changed by faired surfaces and the velocity head smoothly converted to added pressure by means of expanding passages. The volute is not relied on for this purpose.

Pump impellers are of several types, the most common variations of which are shown in Fig. 3. The impeller is really the heart of a centrifugal pump and its design largely determines the efficiency and performance of the pump. The simplest type, the open impeller, appears at *a*. A single-suction impeller appears at *b*. With these two types there is an unbalanced thrust along the shaft and a common variation, designed to neutralize this thrust by opposing it with an equal and opposite thrust, is the double-suction impeller. This last, Fig. 3*c*, is in reality a pair of impellers, back to back, operated in parallel. A fourth type of impeller, sometimes used for low heads and large capacities, is the axial flow impeller shown at *d*.

Impellers are usually made as castings from whatever metal or alloy is necessary for handling the particular fluid in question. The outside shrouds or walls and the bore of the hub are accurately machined, but the inside of the shrouds and the vanes themselves cannot be machined. These are usually hand-filed to a template. The impeller is kept from turning loosely on the shaft by a key set in the shaft and the impeller hub, and is kept in position longitudinally by a shaft sleeve or sleeves. The shaft sleeves are threaded on the shaft or else they are made to slide on the shaft, and are held in position by a sleeve nut as shown in Fig. 4.

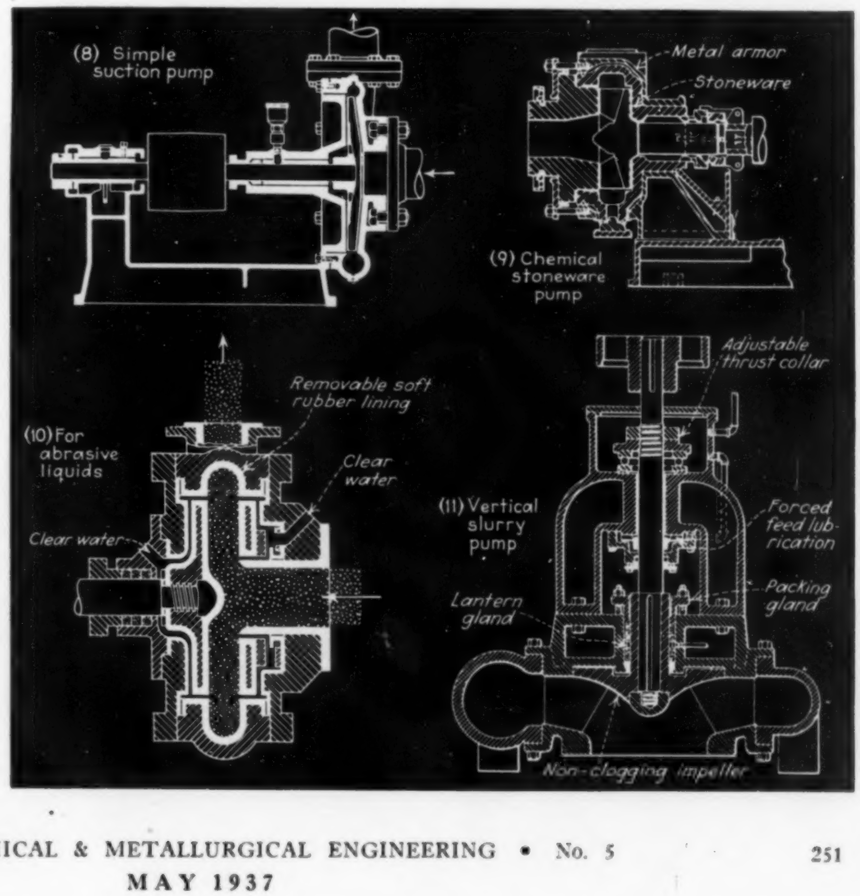
The shaft sleeve protects the shaft from contact with the liquid being pumped as well as from wear by the packing in the stuffing box. Fig. 4 shows a typical stuffing box assembly. The labeled "throat bushing" is sometimes called the "stuffing box bottom," or the "guide bushing." This part acts both as the bottom of the stuffing box against which the packing rests, and also as a guide to the proper flow of the liquid in the casing. In some pump construction it is actually a part of the casing. The packing is usually made up of rings of square cross-section, the number of rings depending upon the length of the stuffing box. It is usually of advantage to have a long stuffing box to prevent leakage of the liquid from the case, or to prevent any air from getting into the suction chamber and interfering with the proper operation of the pump. With a long stuffing box it is not necessary to have the packing so tight, thus decreasing the wear on the sleeves. Frequently the packing is divided into two parts with a grooved ring known as a lantern ring set between. The function of this ring is to provide a space between the packing into which may be led grease, fresh water or liquid from the pump discharge to form a seal against air leakage.

For special pumps handling acids or corrosive liquids, it is sometimes necessary to have special variations of the standard construction indicated above. Thus, Fig. 5 shows a double stuffing box which consists of two independent stuffing boxes separated by a lubricated packing gland. One box is of the conventional type and is built into the pump casing. The other is entirely outside of the casing and is flexibly mounted so that it is free to follow any shaft eccentricity. The entire stuffing box is inclosed, and all chance leakage is drained away from the pump.

To prevent excess leakage from the discharge chamber of the pump to the suction chamber, wearing rings with fairly close clearances are provided. Fig. 6 shows one type of wearing rings known as labyrinth rings. The case wearing rings *a* are set into the casing and arranged to prevent turning in the case. The impeller wearing rings *b* are threaded on the impeller. When these rings wear excessively they can be replaced, so that the original clearances are restored. Some manufacturers use flat wearing rings instead of the labyrinth type. Many others use wearing rings in the case only, their thought being that it is frequently difficult to remove the impeller rings in the field and replace them with new ones. Where this is done, the case rings are made of a softer material than the impeller so that they will receive most of the wear.

The various types of bearings used in modern centrifugal pumps are shown

Some common types of the single-stage centrifugal pump



in Fig. 7. A plain babbitted type bearing is shown at *a*. At *b* is a ball bearing, and *c* shows one type of thrust bearing. The plain bearings are usually of the vertically split type, and lubrication is provided by rings running in a bath of oil. The rings carry the oil to the shaft from where it is distributed to the bearing surface through grooves cut in the babbitt. Ball bearings do not require oil rings. They either run in a bath of oil or are provided with grease cups.

Centrifugal Types Find Wide Use

The centrifugal pump, because of its simple design, lends itself well to fabrication from various corrosion resistant materials and alloys which are required in the handling of certain chemicals.

A simple acid pump is shown in Fig. 8. This is a single-stage, single-suction volute pump and may be made of hard lead, copper, aluminum, iron, or any special alloy. Hard rubber and rubber-lined pumps of this type are frequently used. In such pumps the only part that is likely to give trouble is the shaft sleeve through the stuffing box, since that cannot be made of rubber. Ordinarily it is made of some corrosion-resistant alloy, but for some acids it is practically impossible to find a suitable metal that can be used for this part. On many acid pumps a special drip box is provided under the gland to catch any leakage from the stuffing box.

For pumping materials containing abrasives, a pump lined with soft rubber is advantageous. Fig. 10 shows a cross-section of a Hydroseal pump with a removable soft rubber lining. The water containing the abrasives passes through the suction sleeve, is drawn into the impeller, passes around the volute and out through the discharge nozzle of the pump. All parts through which the liquid flows are lined with soft rubber so that the abrasives cannot come in contact with any of the metal. A small quantity of clear water or any other solution free from grit is introduced at both sides of the impeller and by maintaining a clear liquid film over most of the rubber-lined parts, cuts down on wear from the grit particles in the main stream. Pumps of this type are suitable for handling sand, sludge, slurry or similar materials.

A valuable pump for handling many corrosive liquids is the chemical stoneware pump, shown in Fig. 9. The case consists of a substantial stoneware housing of the solid shell type with a suitable opening in front for the introduction of the impeller. The suction cover is also of chemical stoneware. The joint between this cover and the casing proper is carefully ground and has a special asbestos gasket. All parts of the pump in contact with the material handled is of stoneware. The exterior is reinforced and protected by a cast iron outer casing.

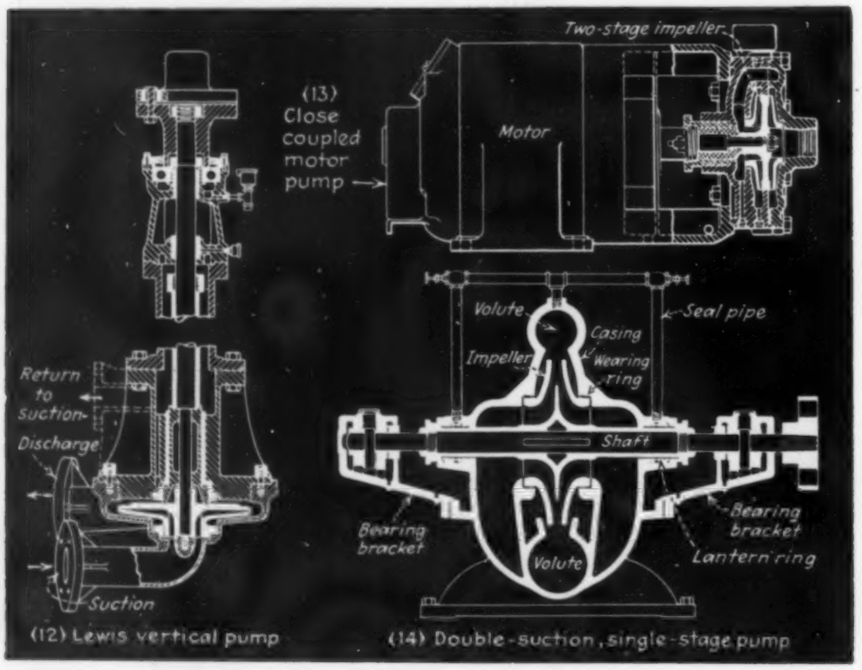
Fig. 11 shows a vertical sludge and slurry pump. Perhaps more conventional than this is the horizontal type, but in either one the case is made extra heavy and the different parts are proportioned in their thickness to the amount of wear to be expected on that part. The impeller is of the non-clogging type with large clearances and waterways. The stuffing box is of special construction, provided with a grease seal. A variation of this pump is widely used in handling pulp, paper stock and similar materials.

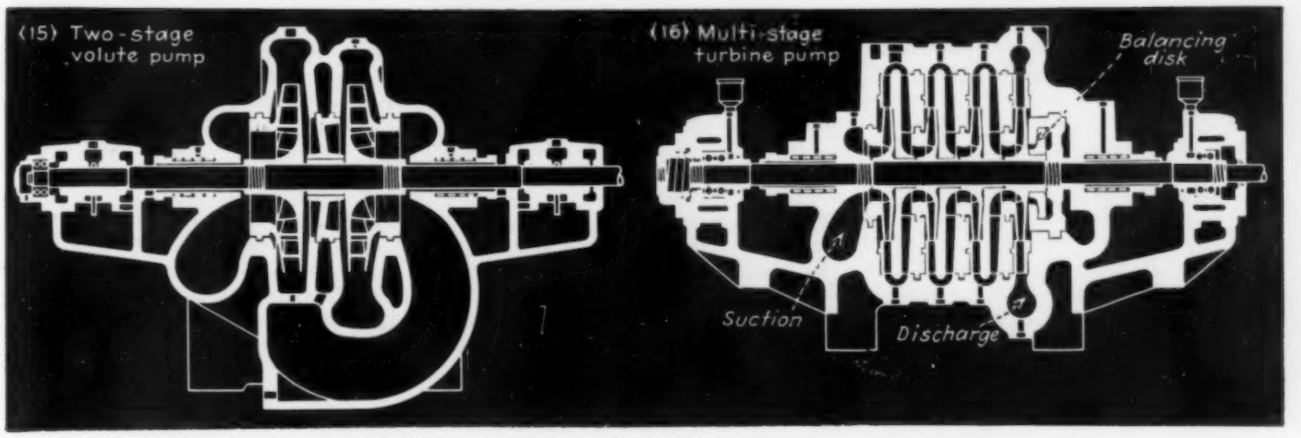
Fig. 12 illustrates a vertical packingless type centrifugal pump that is adapted to the handling of chemicals which are particularly corrosive to packing. This pump is either installed adjacent to or within the suction tank, the shaft of sufficient length so that the motor is above the level of the liquid in the tank. An overflow connection from the column pipe runs back to the tank so that the liquid will not rise up into the bearings. With the elimination of the stuffing box all difficulties and loss of time due to wearing of the packing is eliminated. Various modifications of this pump are built in this country and abroad.

A modern trend in connection with the single-stage, single-suction pump is to combine the pump and motor into a close coupled unit. Here the motor is built with a special extended shaft and with a special end-shield, and the pump is assembled right on the motor shaft. This type of unit makes a rugged, compact, efficient pump that saves space, requires a minimum of attention as to the checking of alignment and is fairly foolproof in operation. Being built with a ball-bearing motor, the unit can be installed either horizontally or vertically, on the wall or on the ceiling. These units are available with totally inclosed or with explosion-proof motors, and the pumps are available with open or inclosed type impellers, also with impellers of the non-clogging type for handling materials containing a percentage of solids in suspension. As the pumps themselves are more or less of the conventional single-suction type, they can be built of any of the materials necessary for the particular liquid that is to be pumped. To take care of higher pressures at moderate speeds, these close-coupled pumps are also made up in a two-stage design, as shown in Fig. 13.

For many of the requirements in the chemical and process industries, particularly for the larger capacities and pressures, the double suction type of centrifugal pump is used. Fig. 14 shows a typical cross-section of a pump of this type. The liquid coming from the suction line divides into two parts and enters the impeller from two sides, hence the term "double suction." Since this type of pump is symmetrical about the center, it is theoretically in hydraulic balance. However, due to possible casting differences and flow variations there might be a slight thrust, and this is taken care of by the thrust bearing. Frequently of distinct advantage is the fact that the stuffing box is next to the suction chamber of the pump, and so is subjected to suction pressure only. Where the pump is

Further variations of the common centrifugal pump





Multistage suction pumps are used for meeting high head requirements

handling liquid with a suction lift so that the pressure on the suction chamber is less than atmospheric pressure, the stuffing box is equipped with a lantern ring (see Fig. 14), which makes a water seal when connected with the pressure chamber of the pump. Where the pump may be handling a liquid that is not suitable for sealing the stuffing box, the line from the pressure chamber is closed off, and the pump is arranged with a grease cup at the lantern ring or else piped up for outside fresh water sealing.

For taking care of the special problems encountered in the modern refinery, double suction pumps have been developed with refinements especially designed to facilitate the handling of hot oil. The stuffing boxes and the thrust bearing are water-cooled. A water line is connected from the cooling water chambers to the glands to smother any leakage of explosive gases. The case is designed with a vent which connects the two sides of the suction chamber and helps to prevent vapor binding. To take care of the necessary expansion when handling very hot liquids, the casing is designed so that it is free to move outward along the longitudinal centerline. Pumps of this type are available for handling liquids up to 750 deg. F.

The pumps discussed up to this time have been single-stage units, both the single suction and the double suction types. Where the head requirements are such that they cannot be handled in a single stage, it is necessary to use more than one stage. Instead of piping up two or more single-stage pumps to handle the higher pressures that might be required, a multistage pump is used. The multistage pump corresponds to combining two or more single-stage pumps in one case. It is available with either single- or double-suction impellers.

Fig. 15 shows a cross-section of a two-stage pump with single-suction opposed impellers. In order to neutralize thrust as far as possible, some manufacturers build their single-suction multistage pumps in this way. They use an equal number of stages with the suctions of half the impellers pointing one way, half the other. With more than two stages this arrangement usually requires considerable head room for the pipe connecting the opposed groups. One way to avoid this condition is shown in Fig. 16. This four-stage pump, which is of the diffuser vane type, has all the suction openings pointing in the same direction. The unbalanced thrust, which would be of considerable amount unless offset by some means, is automatically compensated by a balancing disk at the right of the fourth stage impeller.

The multistage pump built with double-suction impellers is ordinarily more efficient than the single-suction type. However, because of the necessary extra length required for each stage, the number of stages in such a pump is limited in order to keep down the distance between bearings. A long pump would require the use of an extra heavy shaft with relatively large internal leakage.

Peripheral-Impeller Turbine Pumps

An interesting pump and one widely used in chemical industry is the turbine type with peripheral impellers. This is not the diffuser vane type previously mentioned. The best known of this type are the Westco and La Bour pumps. Fig. 17 shows the Westco turbine pump, which is simply a cylindrical case in which fit the impeller and two removable liners, one on either side of the impeller. The liquid is handled entirely in a liquid chamber or race that is machined in the two liners. If wear or corrosion occurs, the pump can be restored to its original condition and clearances by installing new liners and possibly a new impeller, all this being an easy and relatively inexpensive matter. To the right of the pump sketch is an enlarged cross-section of the liquid chamber showing the action of the liquid in this type of pump.

The liquid enters the chamber or race from the suction nozzle of the pump and first comes in contact with the bottom of the impeller vanes. By centrifugal force the direction of flow is through the vanes to the periphery of the impeller where it enters the pump channel. The channel is so shaped that the liquid is directed back into the bottom of other vanes of the impeller and additional energy is imparted to the fluid. This recirculation through the large number of vanes keeps up continuously while the liquid is passing from the suction inlet of the pump to the discharge outlet. Thus, a multistage effect is produced with only a single impeller. The liquid entering the pump chamber is equally distributed to both sides of the impeller, so it is in practically even hydraulic balance. A valuable feature of these pumps is that they are suitable and efficient for handling small capacities against high heads at moderate speeds. This same type of pump is also made up with special materials and features for handling highly volatile liquids and hot liquids. A desirable feature is that the operating speeds are not excessive, even though the pump is only single stage.

Another well-known type of turbine pump used frequently in chemical industry is the La Bour pump, known principally as a self-priming pump. As shown in Fig. 18, the impeller is evidently of the peripheral type, the liquid being handled at the periphery of the impeller. The suction pipe is connected to the trap *D*. After the pump has once been primed, this trap will retain a supply of liquid at the impeller to insure that the pump will be self-priming. On top of the pump casing is the air chamber *C* in which air separates from the water when the pump is being primed. The discharge pipe connects to the top of this chamber. When the pump is started, water trapped in the casing is discharged up through

A into the air separator where it is freed of air and flows back through passage *B* into the pump. This process continues until the pump is primed. When the prime has been established there is too much water to pass out of opening *A*. Consequently, the surplus goes out through *B*, and the pump continues to operate similar to a normal centrifugal pump. There are several other self-priming pumps available which operate on a similar principle of recirculation.

Rotary Positive-Displacement Pumps

While not in the same great demand as the centrifugal pump with its various modifications, the rotary pump is still used very extensively in the chemical industry. Rotary pumps have certain characteristics which permit them to handle thick viscous liquids that are ordinarily difficult to handle with other types of pumps. Due to the fact that they have close mechanical clearances between the rotating members, they are most suitable when used to handle liquids that have some lubricating qualities, although they are also used with non-lubricating liquids because of their self-priming features.

An interesting pump of this type is the Tri-Rotor shown in Fig. 21. In operation, the turning of the rotor produces reciprocating motion in both the piston and shuttle-block, giving four displacement impulses per revolution. The design is such that the four impulses overlap, thus eliminating line pulsations. This pump is available in sizes up to 100 g.p.m., and is of adjustable pumping capacity.

A common rotary type is the gear pump. In one such type the case is a cycloidal-shaped housing containing two spur gears, the driving gear and the driven or idler gear. The pumping action is positive, the gear teeth carrying the liquid in slugs around the inner surface of the housing from the suction to the discharge side. The gears and the housing are designed with close clearances. The slip at the ends of the teeth and over the tops of the gears is negligible, so that the liquid is delivered at a uniform pressure without shock or vibration. Pumps of this type are suitable for pressures up to 1,500 lb.

Another widely used gear pump makes use of herringbone gears as in Fig. 19. With this type of gear the pumps are available for much higher speeds than with the spur gear type. Where the pumps are to handle liquids having lubricating qualities, they are made with internal bearings. External bearings, as in Fig. 19, are used where the pumps are to handle non-lubricating liquids. Sometimes external timing gears are used with these pumps in order to avoid as much as possible the wearing of the pumping gears.

For pumping heavy viscous solutions which are in a solid or semi-solid state under ordinary temperatures, steam jacketed rotary pumps are available which are capable of handling tar, paraffin, cement, lard, molasses and similar products.

A widely used rotary gear pump is of the internal gear type as shown in cross-section in Fig. 20. The rotor of this pump carries on its outer periphery what could be considered a gear, the teeth *T* of which are supported at one end on the rotor disk. This rotor revolves concentrically in the casing. Supported off center within the rotor is a free running gear *G* which meshes with and is driven by the rotor gear teeth. A crescent *C* supported from the end cover of the pump acts to insure a seal between the suction and discharge. With the rotor turning in a counter-clockwise direction, the gear teeth *G* are withdrawn from between the rotor teeth. This action is similar to a piston on the suction of a reciprocating pump and fluid flows in to fill the space between the teeth. As the rotor continues to turn, fluid is trapped between the teeth, crescent and casing, and is carried around and forced out of the discharge by the internal gear teeth meshing with those on the rotor.

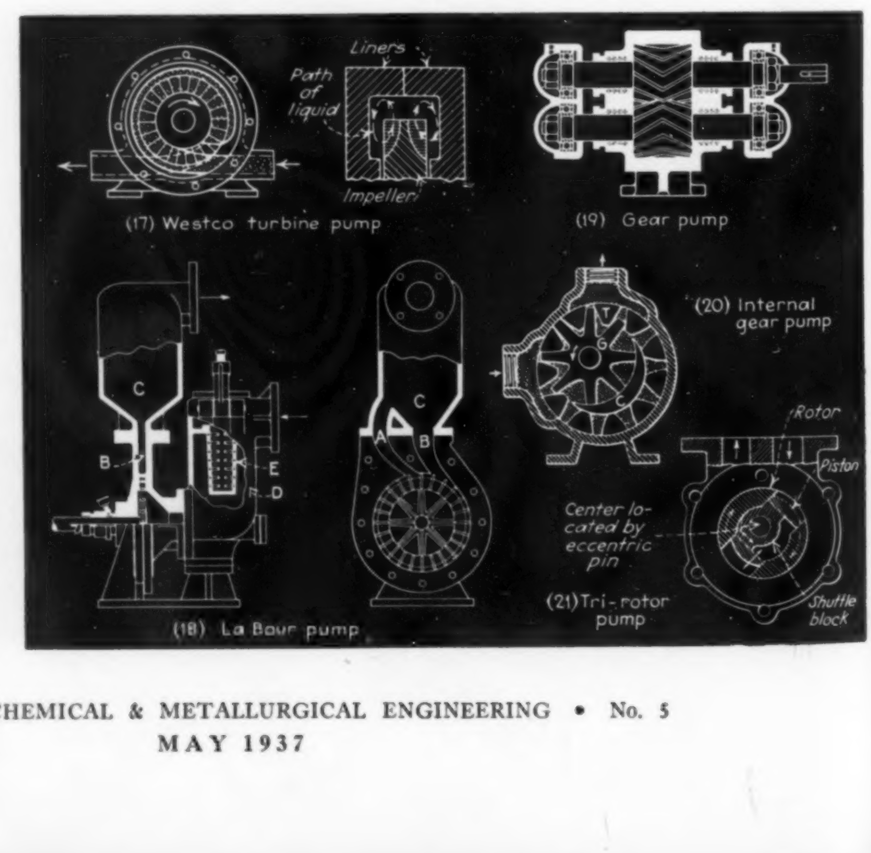
A variation of the gear pump is the screw pump, the most common form of which appears in Fig. 22. Here two screws meet to form a fluid-tight seal and the screws run with very little clearance in their casing. This is similar in principle and operation to the gear pump. The fluid flows into the screws at the suction ends, is trapped between the threads and the casing, and is carried forward to the discharge as the screws turn, much in the manner of a screw conveyor. This pump is fundamentally hydraulically balanced, since the four screws are all of the same diameter and pitch, and the liquid passes through the pump in two equal and opposite streams. The capacity of the pump depends on the screw pitch and the speed of the operation. The pressure developed with any given pump depends upon the number of threads and the viscosity of the liquid handled.

Still another form of screw pump uses one threaded driving rotor and two threaded idler rotors. The idler rotors act as seals to the power rotor, and are driven by the fluid pressure and not through any mechanical contact with the power rotor. The contours of the rotors are of special design to provide a fluid-tight closure between them while retaining clearances that are mechanically practicable. This pump design permits operating the unit efficiently at high speeds, so that the power rotor can be connected directly to motors or turbines without the use of any intermediate reduction gears. It is available as a close-coupled unit with standard types of electric motors.

The rotary pumps mentioned thus far have been of the gear type. Another type is known as the sliding vane rotary pump. This is shown in Fig. 23. The vanes are free to move radially in the rotor which is set off center with the casing. As the rotor turns in a clockwise direction, fluid flows in between the upper side of the rotor and the case, is trapped by the vanes and is forced out the pump discharge.

Fig. 24 shows a swinging-vane rotary pump. In this design the rotor consists

Peripheral turbine and miscellaneous gear pumps



of several arms that support swinging vanes. The rotor is smaller than the bore of the casing, but one side is closed with a crescent. This crescent is solid between the intake and discharge, and, with the rotor arms, acts as a seal between the two. As the rotor turns, fluid flows from the intake into the space between the arms. Then, as the swinging vane passes the intake opening it is thrown out by centrifugal force, and traps the liquid, carrying it around and forcing it out at the discharge.

The Kinney rotating plunger pump is shown in section in Fig. 25. The principle of operation is briefly as follows: The rotation of the shaft carrying the cams around with it imparts a rotating motion to the plunger tangent to the bore of the cylinder. The hollow arm or slide of the plunger is guided by and actuates the slide pin. The movement of the plunger during the first revolution forces the air out of the cylinder through the discharge port in the hollow arm or side of the plunger. At the same time the vacuum produced causes the liquid to flow into the pump. With the pump constructed in duplex, a continuous, non-pulsating flow of the liquid in the suction and discharge line is assured. These pumps are capable of developing high vacuum, and are used for handling heavy viscous fluids. They are also available in steam-jacketed types.

Fig. 26 shows a two-lobed rotary pump somewhat similar in principle to the gear pumps previously discussed and illustrated. However, the fluid is delivered to the discharge in a smaller number of larger quantities. Thus the flow from pumps of the lobe type is ordinarily not as constant as with the other types previously discussed.

Since rotary pumps are all of the positive displacement type, they cannot be operated against a closed discharge, like centrifugal pumps. As a means of avoiding trouble where such operation may be possible, an automatic unloader or relief valve should be provided in the discharge to bypass the discharge back to the suction. Otherwise the pressure would build up in the pump until it might fail or the motor be overloaded. Rotary pumps can be used for handling any liquid that is free from grit and abrasive particles.

Reciprocating Pumps

One of the oldest and still most widely used pumps in the chemical industry is the reciprocating pump, both the steam-driven and the motor-driven types. The direct-acting steam pump is one in which the liquid end is placed directly in line with the steam end. Both the liquid piston and the steam piston are operated by the same rod, and both are operated together independent of any crank movement. There are two general types of direct-acting steam pumps, the simplex and the duplex. The simplex, Fig. 27, consists of one steam cylinder and one liquid cylinder, while the duplex consists of two steam cylinders and two liquid cylinders. Duplex pumps are more generally used for pressures up to 250 lb., despite the fact that the simplex is simpler in construction.

Reciprocating pumps may be of either the piston type or the plunger type, the difference being that a plunger moves past stationary packing while a piston carries its packing with it. The simplex pump in Fig. 27 uses a piston.

Plunger types vary according to the location of the packing. The outside center-packed plunger pump is shown in Fig. 28. This type is used for higher fluid pressures. The plunger glands are readily accessible, and any leakage from the plunger can be detected and stopped while the pump is in operation. The outside end-packed plunger pump is shown in Fig. 29. In this type there are two liquid plungers connected by side rods, and the plunger glands are readily accessible for inspection and adjustment even with the pump in operation. The valve pot type of pump is a slight variation of this, the basic idea being to build the liquid end of the pump in sections so that any one section can be replaced at any time without disturbing any other section. It will be observed that these pumps are designed with a view toward making as low as possible the cost of maintenance and operation.

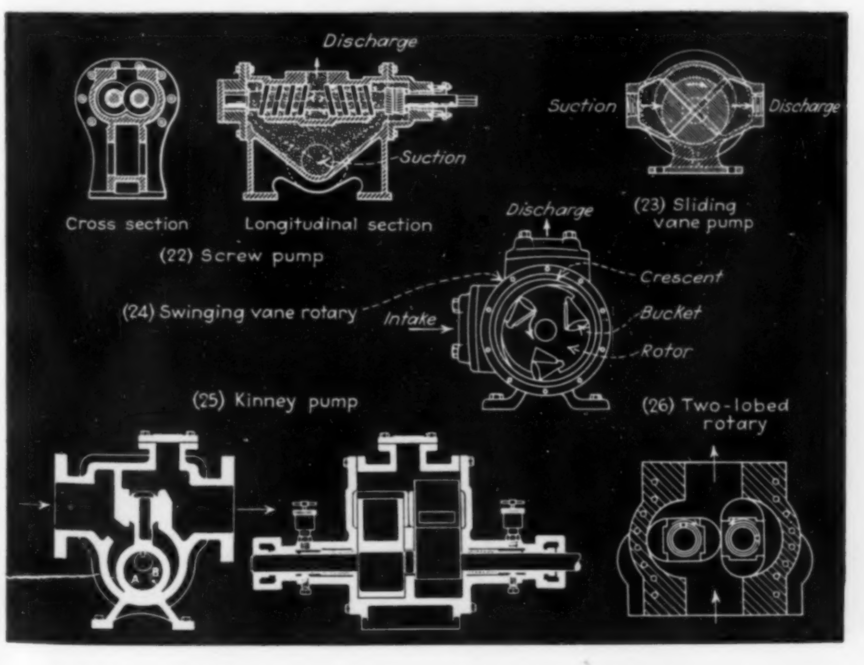
Steam pumps of certain kinds, for instance a ball-valve piston type pump, are built with a steam-jacketed liquid end for pumping asphalt, tar, heavy liquids and oils, which could not be pumped otherwise. By connecting a line from the exhaust steam chamber of the pump to the steam jacket, and making use of the exhaust steam for heating the liquid, the pump is operated without any added expense for heating the steam jacket. A live steam bypass line furnishes the initial heating required when starting the pump.

The foregoing discusses reciprocating pumps that are steam-driven. There are also a large number of pumps of the reciprocating type that are motor-driven. Fig. 30 shows a vertical triplex power pump. There are also several horizontal designs. The advantages of these pumps are their high efficiencies and the facts that they are self-priming and can deliver a constant capacity against widely varying heads. The liquid end of the power pump is practically the same as that of the direct-acting steam pump.

Reciprocating power pumps are also available with the liquid end lined with hard rubber or made of chemical stoneware as shown in Fig. 31.

The diaphragm pump is particularly adaptable to the handling of liquids which contain large amounts of suspended solids. The suction type, which is designed to work against a head of only a few feet, is shown in Fig. 32. By means of an adjustable eccentric connecting the diaphragm yoke shaft and the drive shaft, the stroke of the diaphragm, and thus the rate of discharge, can be controlled accurately. For handling pulps and sludges against greater heads the pressure diaphragm pump is available. It differs from the suction type in that the discharge valve

Additional rotary positive-displacement types



instead of being located in the diaphragm itself, is located in a line emerging from the lower suction chamber below the diaphragm. The rugged and simple construction of the diaphragm pumps and the fact that they involve few moving parts makes them suited for severe service.

As usually understood, a metering pump is a small positive displacement pump of accurate discharge characteristics which is used to deliver a liquid, against either high or low pressure, at a constant average rate. Such pumps usually can be adjusted in delivery rate, either by varying the stroke, or the speed of operation. Spinning pumps used in the rayon industry, for example, make use of both sorts of adjustment. A typical two-piston pump is sketched in Fig. 33. Such pumps are made with from two or three to as many as nine pistons which are pulled back and forth in a rotating cylinder by means of a swash plate, the angle of which is accurately adjustable. Equipped with an air cushioning pressure bottle, such pumps will deliver the small uniform flow of spinning solution required by each spinneret, sometimes operating for many months without appreciable variation in delivery. Gear pumps constructed with even higher accuracy than that required in watch making are also used in rayon spinning. With such pumps, delivery rate is varied by changing drive gears.

For larger discharge, metering pumps are generally of the one-to-three plunger power-pump type, with drive by crank or eccentric. Occasionally diaphragm pumps are so used.

Proportioning pumps are similar to metering pumps except that, as the term is usually understood, they are driven at a variable rate in proportion to the flow of some other fluid. For example, Fig. 34 shows a proportioning pump which is paced by a steam pump delivering the main fluid. Its valve is connected directly to a reciprocating part of the steam pump. Other proportioning pumps are paced by meters measuring the main flow. As in the case of metering pumps, a proportioning pump is usually a piston or plunger pump, and is usually capable of adjustment of the discharge rate independent of the rate at which the pacing mechanism operates.

Fluid-Moving With Compressed Air

While the air lift may not be strictly a pump it does merit consideration in this connection, since air-lift elevation of liquids is still used quite extensively. The principle of the air lift is illustrated in Fig. 35. While the efficiency of this type of installation is lower than that of a deep-well pump, the maintenance cost over a period of years will also be much less.

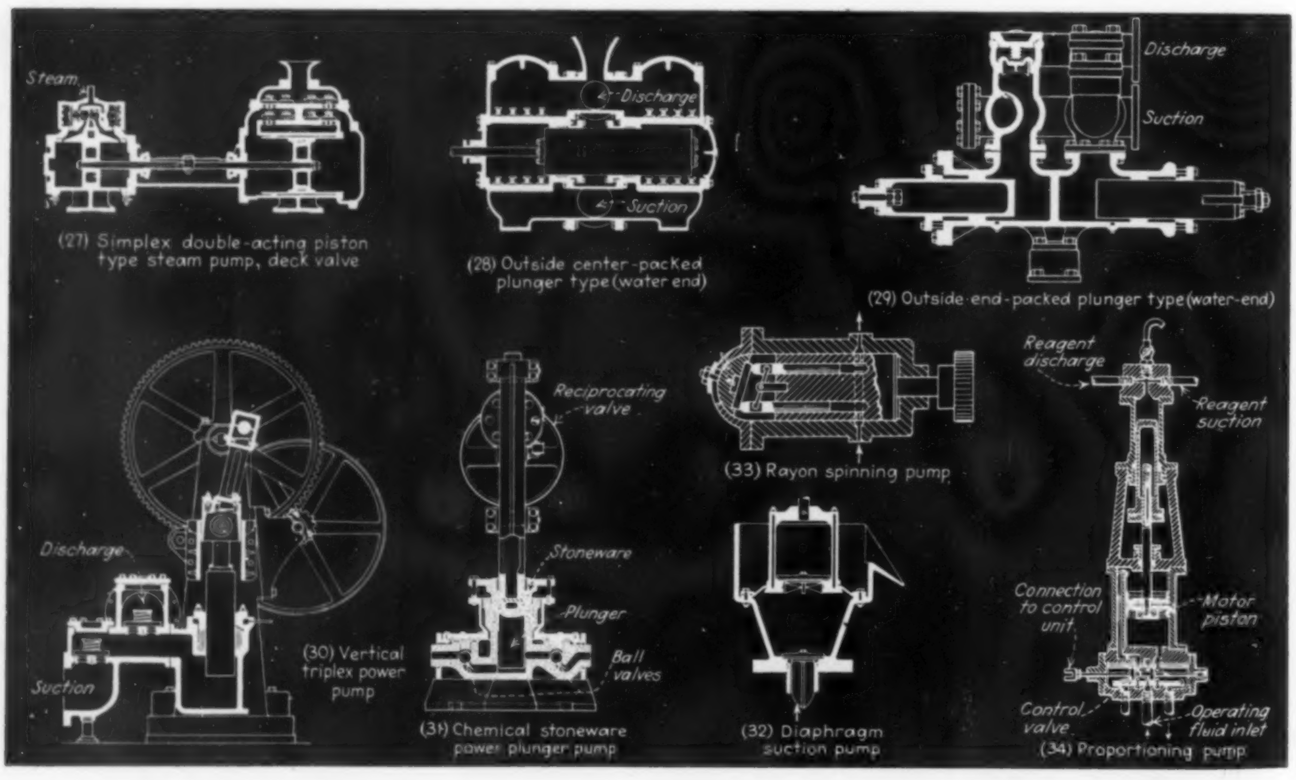
Another means of moving liquids by compressed air is the acid egg, which acts on the principle of displacement of the liquid by air. Fig. 36 shows the common acid egg.

The simple ejector, shown in Fig. 37, is a common means of moving a fluid without the use of moving parts. In principle, it consists of the expansion of a second fluid, usually steam, through a nozzle, the discharge carrying along with it the fluid to be moved. It is used in moving gases at low head, in transferring liquids from one tank to another, and in other cases where the head is low. Its advantage lies in its simplicity. It has the disadvantages of being able to develop only a small head, of being mechanically inefficient, and of diluting the material it handles.

Naturally each different type of pump has different characteristics. By characteristics of a pump is meant the relation between head and capacity, efficiency and capacity, and horsepower and capacity. These various relationships are expressed by means of curves. Fig. 38 shows such a set of curves applying to a centrifugal pump. The maximum head developed is at shut-off pressure with outlet valve closed. As the valve on the discharge is opened the capacity increases and the head decreases gradually. The horsepower increases gradually from shut-off to full load where it flattens out and does not increase any further. The advantage of the centrifugal pump, as shown by these characteristics, is that the head can never increase to any dangerous pressure, nor does the horsepower increase to any point that might seriously overload the motor driving the pump.

The characteristics of a rotary pump

Reciprocating pumps may be either steam-driven or power-driven



(27) Simplex double-acting piston type steam pump, deck valve

(28) Outside center-packed plunger type (water end)

(29) Outside-end-packed plunger type (water-end)

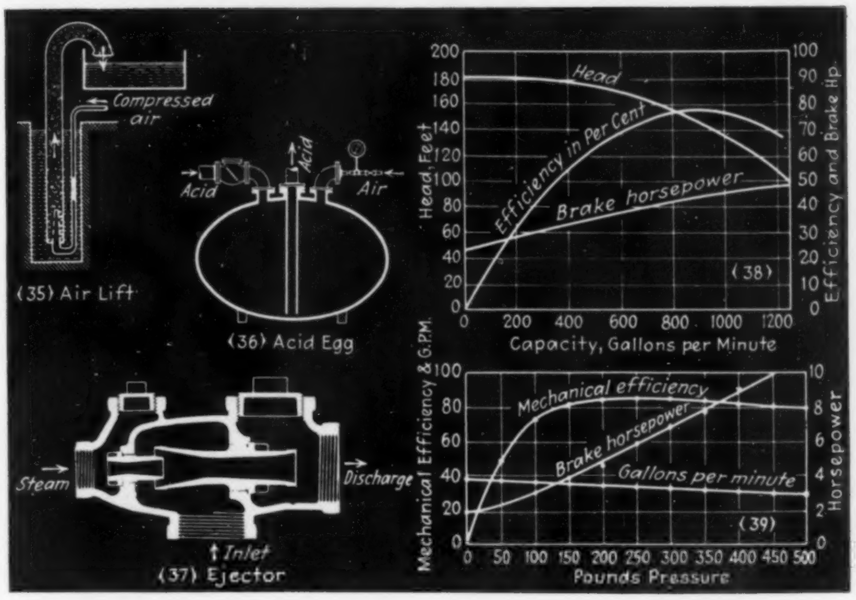
(30) Vertical triplex power pump

(31) Chemical stoneware power plunger pump

(32) Diaphragm suction pump

(33) Rayon spinning pump

(34) Proportioning pump



Miscellaneous fluid-moving devices.

Figs. 38–39—Characteristic curves for a centrifugal pump and a small rotary pump respectively

are shown in Fig. 39. Each revolution of the gears or cams or blades of the rotary pump involves a definite displacement of a fixed volume of liquid. Were it not for some degree of slip, the head-capacity curve of a rotary pump would be a straight horizontal line, the increased pressure being a direct function of the increase of speed of the pump. Fig. 39 shows a very good efficiency for a small rotary pump at pressures from 100 lb. to 450 lb. Since the rotary pump is a positive discharge pump, it cannot be operated against a closed discharge. Where there is a possibility of such operation a relief valve should be installed.

The characteristics of reciprocating pumps are similar to those shown for the rotary pump.

It would be impossible in one article of limited space to do full justice to all the various special pumps and fluid handling devices that are being used in the chemical and process industries. The foregoing discussion takes up some of the more generally known types of pumps, with a few of the better known special types. The writer wishes to express his appreciation to the various manufacturers who have permitted the use of their illustrations in connection with the pumps discussed.

Pump Maintenance

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PROGRESS in the design and construction of pumps for handling acids, corrosive solutions and pulps has kept pace with other developments in equipment for the process industries. Pumping costs reductions can best be obtained today by education of the operators who use the pumps and particularly of the men responsible for pump maintenance.

A typical process industry pump may cost, installed, \$800. This pump will use in a year, perhaps \$400 worth of electricity. Maintenance on this pump may cost anywhere from \$30 to \$500 or more per year, depending to a very large extent on the care and skill applied in maintenance and operation.

One way to reduce pump maintenance costs is to inspect at regular intervals in order to detect wear, corrosion, or other potential cause of failure before the failure occurs. Corrections can then be applied at a convenient time and by the proper man, without overtime or disrupting of production schedule. In this way a first-class repair job is obtained at minimum cost. If sufficiently frequent inspections are not made, failure usually occurs on the night shift; a hurry-up repair job is made with inadequate facilities; and the pump must later be again taken out of service to put it in good shape.

It pays to have two types of scheduled inspections for pumps; a "visual" inspection and a less frequent but also definitely scheduled "shutdown" inspection. For the visual inspection, a skilled mechanic merely looks over the assembly while it is running, checking gland adjustment, bearing temperature and lubrication, motor temperature and other external factors. For a shut-down inspection the pump is taken out of service and dismantled to a sufficient extent to permit careful examination of internal parts.

For centrifugal pumps handling corrosive solutions, gland maintenance is a major cost item. Here again, the rule applies most emphatically: don't wait for failures; re-pack and adjust at scheduled intervals. A packing failure inevitably occurs when the pump is badly needed; re-packing becomes necessary in a few days. This second packing lasts a month or two or even longer. Experience shows that for any particular pump a definite schedule can be setup for re-packing which will virtually eliminate unexpected outages from packing failures. Such a schedule not only avoids interruptions and reduces maintenance costs, it also assists in spotting poor operation, poor workmanship, or other abnormal conditions, which alone can upset a correct schedule.

In spite of everything the maintenance men can do, pump repair costs are largely a matter of skillful operation. An operator who allows a hot liquid to rush into a cold silicon-iron pump can throw away many months of maintenance savings. No gland packing will stay in a pump left running against a closed discharge valve. Throwing the switch on a pump in the casing of which solution has crystallized will often mean at least a new impeller. If the air is lost from the surge chamber of a motor driven positive displacement pump, something will soon give way. If a hose used to clean a spill gets water in the ring-oiled bearings, the bearings will soon seize. Careless tightening of a packing gland is a ruined gland sleeve. Heavier fuses put in the power line when the correct fuses blow due to the impeller rubbing will mean a burned out motor. Such failures are the result of thoughtlessness or lack of experience. An inquest should be promptly held to determine why the failure occurred and how it could have been prevented. The

results of the inquest should be written up briefly and posted for the benefit of other operators and foreman, without of course mentioning names.

Avoid Piping Strains

Small pumps and particularly those of lead or high-silicon iron are usually not designed to stand heavy strains from connecting piping without throwing bearings and gland out of alignment. Even if the initial installation provides a free-running pump, in time supports will sag and foundations settle, and a mysterious series of gland sleeve or bearing failures begins. It is worth while to insert between pump and lines a 2-ft. sleeve of rubber hose, preferably of the spiral reinforced suction type. With adequate supports and careful installation, this avoids undue strain and will also facilitate repairs if flanged joints are used at the ends of the hose.

Particularly with high-silicon-iron pumps, the use of an adequate strainer will pay for itself several times in a year. Without the strainer, sticks and pieces of sampling bottles, not to mention nuts and bolts find their way into the pump at the most inopportune times and with dire results.

It frequently pays to protect pump bases with sheet or even homogeneous lead. The drip cups provided by pump manufacturers are often inadequate where gland leakage is a heavy pulp or a crystallizing solution. The cup drain soon plugs and the pump base gets the drip. The maintenance man sees that the base has weakened, but puts off repairs until a broken impeller has resulted.

Frequency of re-packing of pump glands can be reduced and sleeve wear minimized by preventing overheating and drying out of packing. A small stream of water playing on the gland is in some cases satisfactory. In other cases, a double gland may be used (standard with several manufacturers) and a little water supplied under pressure at the grease connection. Where water getting into the pump in this manner must later be evaporated, an .008 in. orifice may be used in the water line, protected with a screen and a plug of cotton, and preferably with a simple telltale to show that water is flowing. The double gland with a water connection is particularly useful on self-priming pumps where admission of air at the gland is objectionable. For pumps handling strong sulphuric acid the same type of gland is desirable, but with a spring-loaded grease cup to supply a steady trickle of heavy oil. The grease cup should be arranged for re-filling by a grease gun.

Obviously, the above devices are neither fool-proof nor completely automatic. They will prove satisfactory only if given regular and intelligent attention. They are aids to but not substitutes for skillful maintenance and operation.

The old-fashioned "lantern ring" for supply grease to the packing should be avoided. It will not be in alignment with the grease connection after the gland has been tightened once or twice. When a new mechanic comes on the job, no one will tell him that there is a lantern ring in the gland. He will remove and replace only the outer half of the packing. After this has been done a few times, the lantern ring is at the bottom of the packing recess, no grease can get in through the grease connection, and troubles start.

When a pump must deliver intermittently to one or more outlets, an air-chamber and pressure switch may be used to automatically turn the pump on and off. When the valve in the delivery line is closed, the pump forces liquid into the air chamber compressing the air until the pressure switch trips and shuts off the pump. A check valve tends to prevent liquid running back through the pump. Inexpensive pressure switches such as used on garage air pumps are readily available, but should preferably be protected by an oil seal if the liquid handled by the pump is corrosive. The air-chamber may be a 10 or 20 ft. length of 10 in. pipe, with lead or rubber lining if necessary. It will require some education to get the maintenance men to realize that the air-chamber must actually have some air in it to function properly. A recording pressure gage is a help in getting this lesson across; if the record shows starting and stopping at frequent intervals, either the air supply has been lost or the check valve at the pump leaks.

Air-Chamber and Pressure Switch

The above described air-chamber and pressure switch is used to good advantage also for protecting electrically driven positive displacement pumps used for filling filter presses. Where the slurry to be filtered is corrosive, the use of a pressure release valve is unsatisfactory to say the least. The air-chamber and pressure switch in this application has a further advantage when handling sludges containing heavy solids that tend to plug the line between pump and presses. By locating the air-chamber close to the presses, the line from the pump is flushed at regular intervals by the full capacity of the pump, and if of the proper size will not plug. The line between the air-chamber and the presses will tend to plug as the rate of filling decreases toward the end of the cycle, but this line may be made short enough to avoid trouble. The arrangement is, of course, not absolutely fool-proof; the air in the air-chamber must be kept up, and it is wise to have either a second pressure switch or a rupture disc at the pump to avoid serious damage if the line between pump and air-chamber does plug.

Occasionally the use of a centrifugal pump for feeding filtration equipment is definitely objectionable because of its effect on filter capacity. Centrifugal pumps may break up crystals in a slurry, and the resulting small crystal size may make more difficult subsequent filtration and washing the crystals free of adhering mother liquor. In the case of finely divided precipitated solids, the violent agitation in passing through a centrifugal pump will sometimes substantially decrease filter ability. Where a continuous filter is used, with overflow returning again to the pump, the cumulative effect of repeated passage through the pump may be pronounced.

Pumping Filter Feeds

In some cases a steam driven reciprocating pump with liquid end of the inside packed piston type is ideal for continuous filter feed. The steam supply valve may be placed at the filter and the steam line to the pump used to steam trace the slurry line to the filter. A steam separator and a steam trap will, of course, be needed at the pump. This arrangement permits convenient control of pumping rate by the operator. If desired, level control in the filter bowl may be made automatic by a float actuated steam valve.

Caution is necessary in handling the high density liquids at high heads with large capacity centrifugal pumps of high silicon iron. These conditions necessitate large motors with starting torques approaching the pump design limits. For such conditions an across-the-line starter may be undesirable, particularly for 25 cycle current. If trouble is experienced, a friction drive coupling may be used that permits gradual loading of the motor after it is up to speed.

Diaphragm pumps appear to be the only practical answer to the problem of filter pressing heavy pulps of abrasive solids suspended in corrosive liquid. In this type of service the high initial cost of these pumps is well justified. These pumps appear to be more susceptible than most to excessive costs due to poor operating and maintenance technique. A pump of this type under exceptionally severe service conditions operated for many months at a repair cost of around ten dollars per month. Later, a few apparently minor piping changes were made and maintenance personnel reorganized, and the repair costs jumped close to $100 a month. The pump would have been thrown out, were it not for the sad experience with a centrifugal pump used in its place while an overhaul was being made. A few piping changes and the renewed realization that constant and skillful follow-up is essential were all that was necessary to again obtain low repair bills.

GAS MOVING EQUIPMENT

EQUIPMENT used for the moving of gases naturally divides itself into three groups, based on the pressure involved. By far the greatest part of all compression equipment handles gases at pressures from a few ounces below atmospheric pressure to, say, 125 lb. Another class handles the higher vacuums, while still a third group of machines is found in the high pressure field, producing pressures from the limit of the medium pressure machine to 5,000 lb. or higher. Three following articles survey these divisions.

Medium Pressure Compressors

By *G. L. MONTGOMERY*
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NEW YORK, N. Y.

EQUIPMENT for the compression of gases and vapors in the range between 0 and 125 lb. per sq.in. gage is employed primarily for the purpose of raising the pressure in order to effect movement. The purposes of such movement may be the removal of the material, as when gases or fumes are exhausted from a manufacturing space; the ventilation of a working space by the introduction of fresh air; the movement of a gas against pressure, as when fuel gas is caused to move through gas washers and scrubbers; or the raising of gas pressure in order to carry out some operation, as in the compression refrigeration cycle.

Equipment available for use in this range of pressures includes fans, rotary positive blowers, centrifugal compressors as well as reciprocating air compressors.

Which class of equipment is to be utilized for a given purpose depends mainly upon the pressure required to carry out that purpose. Fans operate with best results in the pressure range from 0 to 5 in. water gage, or less, with some heavy duty types performing efficiently up to 10 in. pressure. Positive rotary blowers and compressors operate best, in single stages, at pressures from 0.5 to 15 lb. per sq.in. gage. Centrifugal or turbo compressors have an effective pressure range of from 0 to 5 lb. per sq.in. in a single stage, but are available in multi-stage designs, built for pressures up to 175 lb. per sq.in. Reciprocating compressors of single stage design operate in the range from 0 to 125 or 150 lb. per sq.in., with a more usual top limit of 90 or 100 lb.

Fans are of two general types: centrifugal; and disk or propeller.

The centrifugal fan is not greatly unlike a centrifugal pump in design. Essentially, it consists of a number of blades, mounted on a rotatable shaft, in planes parallel, or approximately parallel to the axis of the shaft. These blades rotate within a casing or housing, scroll shaped, so as to permit the air to leave the fan without undue losses in efficiency. In such a fan, air enters at the center of the blades and is discharged at the blade tips.

Two designs of centrifugal fans are commonly used: the straight-blade or mill-type fan; and the curved-blade fan.

Straight-blade fans have from six to ten blades, each made of an appropriately shaped piece of plate as shown in Fig. 1. These fans are used to move relatively large volumes of air, at low velocities and pressures. Their most important applications are for exhausting air, gas or fumes from relatively large spaces; and for conveying dust, chips or other finely divided material. They are simple in design, relatively inexpensive, and are readily constructed of materials that will resist corrosion or abrasion.

Curved-blade fans are constructed with a relatively large number of shallow blades, most often curved backward from the direction of rotation. These fans are generally selected to operate in the higher part of the fan pressure range. They are used for supplying air to dryers, for air conditioning and ventilating purposes, for providingd raft for furnaces, and for gas handling. Centrifugal fans with backward curved blades are in general similar to the fan shown in Fig. 2. Such fans have the best characteristics over the widest operating range of any design available.

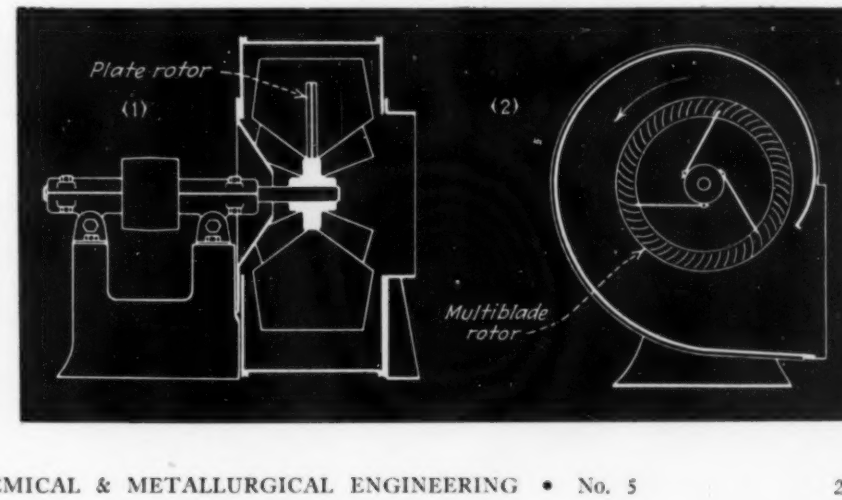
The propeller or disk fan is designed with its blades set perpendicular, or approximately so, to the axis of its shaft. In general, the design is similar to that of an airplane or ship propeller. These fans are used for moving large volumes of air at low pressures and find their chief applications in room ventilation, air conditioning, dust removal, and some forms of drying, as in linoleum drying lofts and tobacco curing.

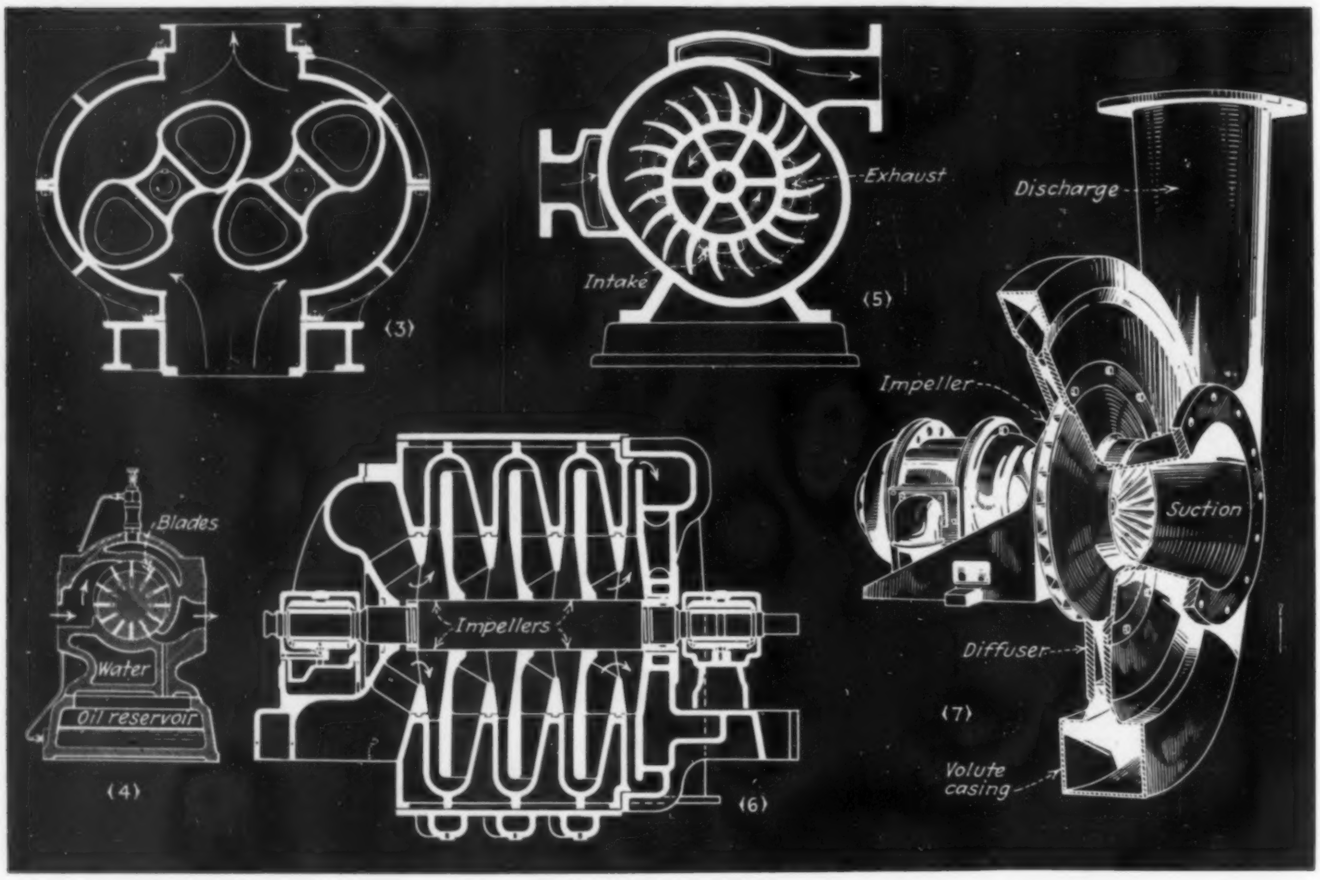
Positive rotary blowers or *compressors* are available in many designs. Typical examples of these devices are the cycloidal, two-lobed impeller blower; the single eccentric compressor; the water-piston and gear compressors.

Essentially, this class of machine consists of a stationary casing within which are a rotating part or parts. The moving members are arranged so as to "wipe" around the walls of the casing with but little clearance, entrapping air or gas between themselves and the casing. This air or gas is carried, by the rotation, from the suction around to, and pushed out of the discharge. Because each revolution delivers at definite pressure, these machines are called "positive."

Positive rotary blowers of the cycloi-

Figs. 1, 2—Mill-type and multi-blade fans





Figs. 3, 4, 5—Typical positive rotary compressors
Figs. 6, 7—Representative multi- and single-stage centrifugal compressors

dal, two-lobed impeller type have an effective pressure range from 0.5 to 15 lb. per sq.in. In multistages, higher pressures up to 30 lb. or more can be obtained. Most single eccentric compressors operate at pressures up to 10 lb. per sq.in. while special designs are good for pressures up to 60 lb. Gear compressors are effectively used, particularly for refrigeration service, for pressures up to 95 lb.

Positive rotary compressors are used for handling gases, for operating dryers, for supplying blast to furnaces and ovens, for aerating and agitating, for pneumatic conveying, in ore refining, sewage treatment, refrigeration, gas manufacture, gas distribution, coal byproduct plant operation and petroleum refining. Factors governing the selection of this type of equipment are: (1) They supply a constant flow of gas, without surges; (2) Moving parts are few, wear is at a minimum, and they can be used for long periods without loss of efficiency or much maintenance expense; (3) Efficiency is relatively high, particularly in the larger sizes; (4) Cost is relatively low, when compared to other devices operating in the same pressure range.

The two-lobed, cycloidal type of blower is shown in Fig. 3. As can be seen from the figure, it consists of a heavy casing, within which rotate two impellers. Each of these impellers is designed as a two-lobed cam, and they are so shaped and so placed that they maintain, throughout each revolution, a very small clearance between each other and between themselves and the casing walls. As can be noted from the drawing, each cam, as it revolves, traps a portion of gas between itself and the wall of the casing. This gas is pushed around the casing wall and forced out at the discharge opening.

The single eccentric design has many variations, but each consists essentially of a rotating element, mounted eccentrically in a casing, so that gas taken in at the suction opening is compressed and delivered at the discharge. Operation is generally facilitated by some flexible means of reducing the clearance. For instance, in the "Rollator" type, a single, spring-mounted vane is used, while the Fuller compressor, shown in Fig. 4, employs a multiplicity of vanes, The method of operation is evident.

The water piston type is illustrated by Fig. 5, which shows a Nash "Hytor" compressor. The rotor of this compressor consists of a circular casting, with projecting blades, revolving in an elliptical casing filled with a liquid. The water turns with the rotor but follows the casing, because of centrifugal force. Twice in each revolution, the shape of the casing causes the liquid to recede from and then re-enter the blades of the rotor. In this way the increase and decrease of the gas space first sucks in gas, then compresses and discharges it.

Gear pumps consist of two meshed gears, revolving within a casing. These gears run at high speed, entrapping relatively small quantities of gas in the clearances between the gear teeth, and deliver this gas as the teeth unmesh. High pressure gear compressors, which work at pressures as high as 90 lb. per sq.in. or more consist of two double helical gears and are similar to the gear pump shown on p. 254. Ruggedness, easy and quiet operation, and positive, steady compression are characteristics.

Centrifugal compressors are similar in design to centrifugal pumps, except that the strength and proportions of parts are chosen to suit the needs of gas handling rather than liquid handling. Two types are available, open impeller and shrouded impeller. These compressors come in single- and multi-stage.

The single-stage design usually operates in the range from 1 to 5 lb. per sq.in., while the multi-stage design may operate as high as 175 lb. per sq.in.

although the usual range is up to 30 lb. Single-stage centrifugal compressors have capacities of 12,000 cu.ft. per min. or more. Many multi-stage designs will exceed deliveries of 50,000 cu.ft. per min.

Centrifugal compressors can be operated at high speeds, making them suitable for direct connection to electric motors or steam turbines. Another advantage is the relatively small space requirement for a given output.

When centrifugal compressors are operated at constant speed, they will maintain a constant delivery pressure over a wide range of capacity. This characteristic makes them particularly suitable for blasting, for water gas plant operation and for refrigeration. The demand characteristics of such operations are particularly suitable for this design of compressor and it will operate in these cases at efficiencies higher than can be obtained with other equipment. In some other industries, however, when the demand conditions are not so well suited to this compressor, and the efficiency obtained is lower, its relatively high first cost must be considered.

In Fig. 7 is shown a single stage centrifugal compressor with shrouded impeller. Open-impeller, single-stage compressors are also made. The design features, generally similar to a centrifugal pump, are evident from this diagram. Note the deep diffuser interposed between the impeller outlet and the volute casing. This serves to convert the velocity of the air leaving the impeller into pressure as it enters the casing. The particular design of compressor shown is available for pressures of 0.75 to 3 lb. per sq.in. at 3,500 r.p.m., and will deliver up to 15,000 cu.ft. of air per min. It is applied in blasting, gas manufacture, air agitation, conveying, ventilating, cooling, and process work.

A four-stage centrifugal compressor of the open-impeller type is shown in Fig. 6. Multi-stage compressors are also made with closed impellers. Design features, as will be noted, are in general the same as in the single-stage machine.

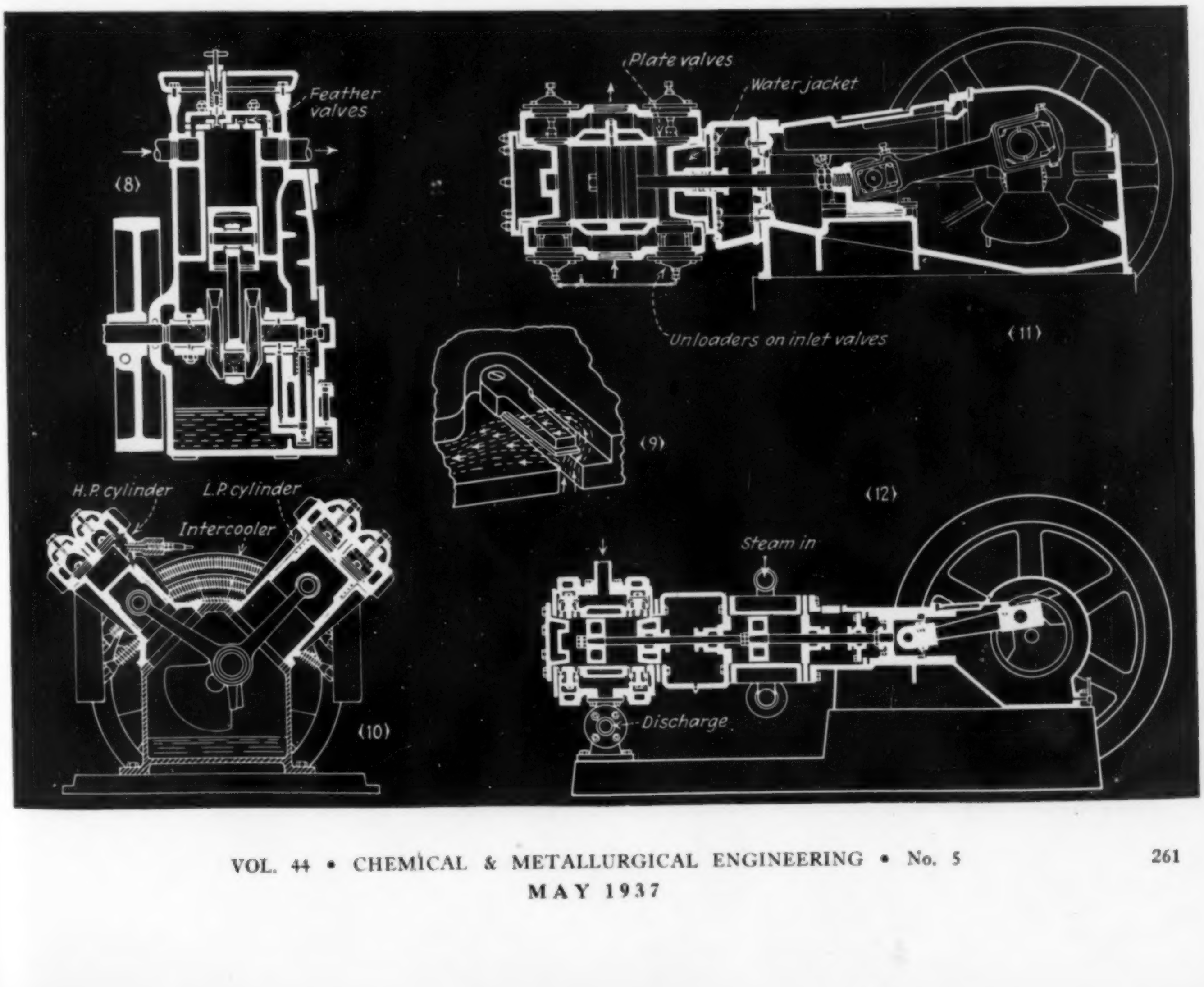
These multi-stage centrifugal compressors find their principal applications in blasting for furnaces, in air flotation processes, in gas manufacture, in agitation and in refrigeration. Extremes of capacity are in the neighborhood of 175 lb. per sq.in. pressure and 100,000 cu.ft. of air per min. More usual top pressures are 110 lb. per sq.in.

Reciprocating compressors are available in a great variety of types and designs. Those under consideration here are generally of single-stage design, operating with delivery pressures not above 125 lb. per sq.in., but more usually in the range 90 to 100 lb. per sq.in.

Operation of a reciprocating compressor is the reverse of the operation of a steam engine. It consists essentially of a piston, moved back and forth in a cylinder equipped with inlet (suction) and outlet (discharge) valves. As the piston moves away from the cylinder head, the space between the cylinder head and the piston is increased. The suction valve is opened during this part of the piston stroke, and air is sucked through it into the cylinder. As the piston travel reverses, and the piston starts back toward the cylinder head, the suction valve is closed. The gas entrapped in the cylinder, having no escape, is compressed. When this compression stroke is near completion, the discharge valve is opened, either mechanically, or by the pressure of the compressed gas within the cylinder overcoming the action of a spring which tends to keep the valve closed. The compressed gas is then discharged into a receiver, which serves to even out the surges in pressure caused by the intervals between piston strokes.

When gas is compressed in this way, considerable heat is developed in the cylinder because of the work done on

Figs. 8-12—Reciprocating compressors, single and two-stage



the gas in reducing its volume. As the final volume of the compressed gas is small, the temperature rise in the gas is relatively high. But for good efficiency in the compressor, the discharge temperature must be as near to the suction temperature as possible. For this reason the compressor must be equipped with some means of cooling. This is usually water jacketing in the larger sizes and air cooling by means of a finned construction in the small sizes.

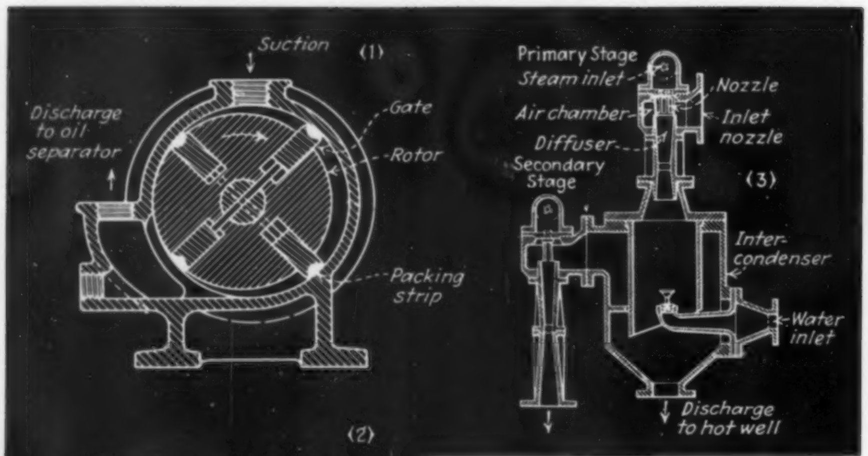
Single-stage air compressors are of two general types—vertical and horizontal. The vertical type is generally chosen for high speed, low capacity use, as it is lighter and requires less floor space **(Fig. 8).** Not much modification in design is necessary in the small two-stage 150-lb. compressor shown in Fig. 10. For heavy duty, the horizontal compressor is more often chosen (Fig. 11).

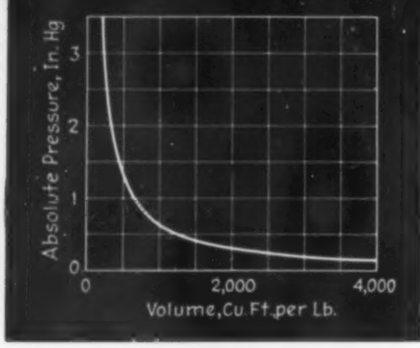
Reciprocating air compressors are either single or double acting: that is, compression may occur in only one end of the cylinder, or in both. Generally speaking, the smaller lighter compressors are single acting, while most others are double acting.

Another variation in compressors is in the valves. Many heavy-duty compressors have poppet valves similar to those used on large steam and gas engines. Others use plate, strip rings, or feather valves, which give maximum opening almost instantaneously. These are all variations of a design in which a thin steel member, confined between upper and lower plates, is caused to rise or lower against spring pressure, uncovering a valve port when it rises. Fig. 9 shows a simple feather valve of this type, as used in the compressor of Fig. 8. It has only one strip, which is itself a spring.

Reciprocating air compressors may be driven by many different means. Small, high speed compressors are often direct connected to motors. V-belt and flat belt drives are used for other compressors in the high speed and medium speed ranges. Low speed, heavy-duty compressors are driven either by V- or flat-belts, or by direct-connected steam cylinders built integral with the compressor frame, as shown in Fig. 12. This latter type of compressor was formerly much used for refrigeration installations, but motor-driven compressors are more frequently used for this purpose today.

Reciprocating compressors are used for almost all purposes where pressures above 30 or 40 lb. per sq.in. are needed. Among such applications are compression of gases for refrigeration or processing work; supply of compressed air for agitation, cleaning or operating tools or equipment; gas manufacture and distribution; petroleum refining; mining and metallurgical work; steel mill work; spraying and atomizing; drying; painting; water or other liquid moving; tire manufacture; and for any other purposes where a gas or vapor must be compressed or moved.





Typical high vacuum producers

Vacuum Producers

EDITORIAL STAFF

VACUUM producers are of three principal types: reciprocating and rotary pumps, and jet ejectors. In addition, for reducing the pressure by a few ounces to a few inches of water below atmospheric, centrifugal rotating equipment is widely used, as in the production of draft. Much of the equipment described in the preceding section is suitable for low vacuum; and without much modification, for higher vacuum as well with certain of the reciprocating and rotary types.

In the range from about 2 in. Hg vacuum to about 26 in., reciprocating equipment is most used. In this range there are two types, the wet and the dry vacuum pump. The former has larger clearances and is designed to handle any condensed water. It is therefore not suitable for as high vacuum as the dry type. The latter is used with surface and barometric condensers from which the condensed water is removed by other means: by a separate pump (generally centrifugal) for the surface condenser; and by a barometric leg for the barometric condenser. Variations similar to those noted in reciprocating compressors are found in vacuum pumps, except that effort is made to make the clearance volume as small as possible since the presence of clearance seriously affects the vacuum that can be produced.

Rotary vacuum pumps are used in the range from 26 in. Hg vacuum, or somewhat higher, to within a few millimeters or even a few microns of the barometer. The rotary type necessarily has low volumetric capacity, but where not much displacement is required is the most economical device for extremely high vacuum.

The construction shown in Fig. 1, which is found in the Beach-Russ pump, permits attainment of vacuum of 5 mm. Hg in a single stage, and of 0.5 micron in a two-stage pump pulling against a blank flange. For semi-wet service the latter type is capable of working within 0.1 mm. of barometer. The pump uses an eccentrically mounted rotor carrying two pairs of gates which maintain contact with the wall of the cylinder by means of packing strips at the outer ends. A constant flow of oil is supplied to all moving parts. Excess oil leaves with the discharged air and is caught, together with any water, in a separator from which the water discharges continuously, while the oil is returned to the pump.

Vacuum higher than about 26 in., where large capacity is required, is produced ordinarily with the steam jet ejector. As appears from Fig. 2, at high vacuum the volume of water vapor is so great that only an apparatus of enormous displacement can develop any considerable capacity. This the jet can do, although for highest vacuum, it is not ordinarily as economical as the rotary type. From one to three steam jet stages are used, the construction being similar to Fig. 3 which shows a two-stage unit with inter-condenser.

High-Pressure Compressors

By C. H. VIVIAN

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PHILLIPSBURG, N. J.

PROBABLY more than 90 per cent of the compressors in service operate at discharge pressures of less than 125 lb., the reason being that the principal applications of compressed air and gas seldom require higher pressures. Consequently, in the terminology of the compressor manufacturer, high pressure generally means anything greater than 125 lb.

The range of gases handled in high-pressure work is extensive but a majority of the units in service today are compressing air, ammonia gas, nitrogen, carbon dioxide, hydrogen, oxygen, propane and other petroleum refinery gases. The normal upper limit of pressure in the United States is 5,000 lb., although there are a few installations of 15,000 lb. machines for the production of synthetic ammonia. Established European practice calls for 15,000 lb. in the ammonia process, but in recent years many plants abroad have adopted the lower-pressure process that is generally used in America.

A four-stage compressor used in a synthetic ammonia process is shown. It is a 4-cornered, 20-in. stroke compressor for atmospheric intake and 4,500-lb. discharge. The first and second stages are double-acting; the third and fourth are single-acting. The compressor is driven at 150 r.p.m. by a 350-hp. synchronous motor. All sketches are simplified diagrams based on Ingersoll-Rand designs.

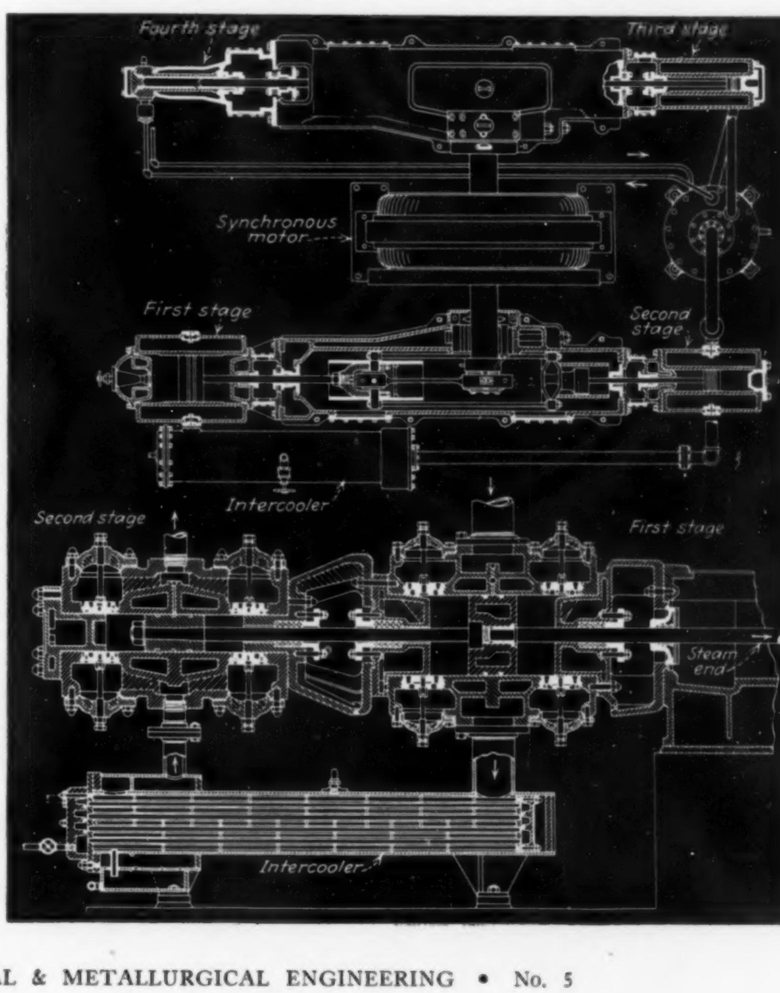
With the exception of oil-field compressors, standard high-pressure compressors are available only in sizes up to 125 hp. and for discharge pressures up to 2,500 lb. Standard units for oil-field service, usually gas-engine-driven, are built in sizes up to 300 hp. and for discharge pressures to 2,000 lb. In the larger sizes of compressors, such as are ordinarily used for chemical plant process work, there is hardly such a thing as a standard machine, and virtually all units are specially designed to meet specific service requirements.

All high-pressure compressors are of the reciprocating type. Some are vertical, particularly where floor space is at a premium, but horizontal units predominate, especially in the larger sizes. Horizontal construction is in most cases less expensive and provides greater accessibility to working parts.

The number of stages ranges from two to six. Two- and three-stage units are often built with the cylinders arranged in line, but above three stages duplex design is usually followed. Some of the chief requirements the designer has to meet are: A balanced load on the frame, and in both directions; a smooth torque effort, which relates to flywheel effect; and suitable arrangements for unloading the cylinders while starting. All of these conditions can be met most satisfactorily in most cases by a duplex machine. A three-stage, duplex, 20-in., steam-driven compressor is illustrated. It consists of a double-acting first-stage cylinder on one side of the frame and single-acting second and third stage cylinders opposed on the other side.

Factors that determine the number of stages, and hence the ratio of compression per stage, include the size of the machine, the nature of the gas to be handled, the permissible or desired discharge temperature, and details of the process in which the compressor is to be employed. The lower the ratio of compression, the easier it is to control final temperatures through interstage cooling. In small units, the ratio of compression sometimes exceeds 5 to 1, but in larger machines, it is more often of the order of 3 or 4 to 1.

In the case of small machines (up to 125 or 150 hp.), two-stage units are commonly used for pressures to 500 lb. Three-stage machines very often run as high as 2,500 lb., in small sizes, although four stages are normally employed in larger machines for the range from 1,000 to 3,500 lb. For pressures above 3,500 lb. six stages are usual. Sometimes the process determines the number of stages. In making solid carbon dioxide, for example, it is desirable to compress the carbon dioxide to 70 lb. in the first stage. This calls for a three-stage machine to obtain the end pressure of 1,200 lb. A three-stage, 12-in. stroke, belt-driven compressor for making solid carbon dioxide is shown on page 264. It operates from atmospheric intake pressure to 1,200 lb. discharge, has one low-pressure, one intermediate-pressure and two high-pressure cylinders, all single acting. All cylinders are equipped with hand-regulated clearance pockets. Such step regulation is required by the varying amounts of gas that are returned or recirculated between the different stages.



Top—Four-stage compressor used in synthetic ammonia process. Bottom—Two-stage, straight-line, standard compressor

In the hydrogenation of petroleum, where the ultimate pressure is 3,500 lb., the process calls for washing the gas at a pressure of approximately 220 lb.. By using four-stage compression, this pressure can be reached at the end of the second stage, or by using six-stage compression it can be reached at the end of the third stage.

Five-stage compression is seldom used, because it does not lend itself to good balance of the machine. In one American installation of 15,000 lb. pressure, the compression is divided between two groups of machines, both of them three-stage. For pressures to 5,000 lb., however, when spare capacity is taken into account, it is usually more economical to combine all stages of compression in one unit.

All conventional types of drive are applied to small compressors. Larger ones are usually direct driven by steam engine or electric motor, depending upon plant conditions. Where electric drive is the choice, synchronous motors are favored.

Among the special problems is packing. It is always advisable to keep stuffing boxes few in number and to secure as low a differential pressure as possible between adjoining cylinders. All stuffing boxes should be thoroughly water-jacketed. Where poisonous or valuable gases are being handled, stuffing boxes are usually vented, so that leakage can be led away or re-cycled.

Piston speeds present a problem, particularly as to high-pressure cylinders. Large machines have been successfully built with piston speeds up to 600 ft. per min. for discharge pressure up to 5,000 lb. On 15,000 lb. discharge machines, piston speeds should preferably be not greater than 350 or 400 ft. per min.

Valving formerly presented a serious problem to the designer. These difficulties were largely overcome with the advent of the high-pressure plate-type valve, which can be used throughout modern high-pressure units.

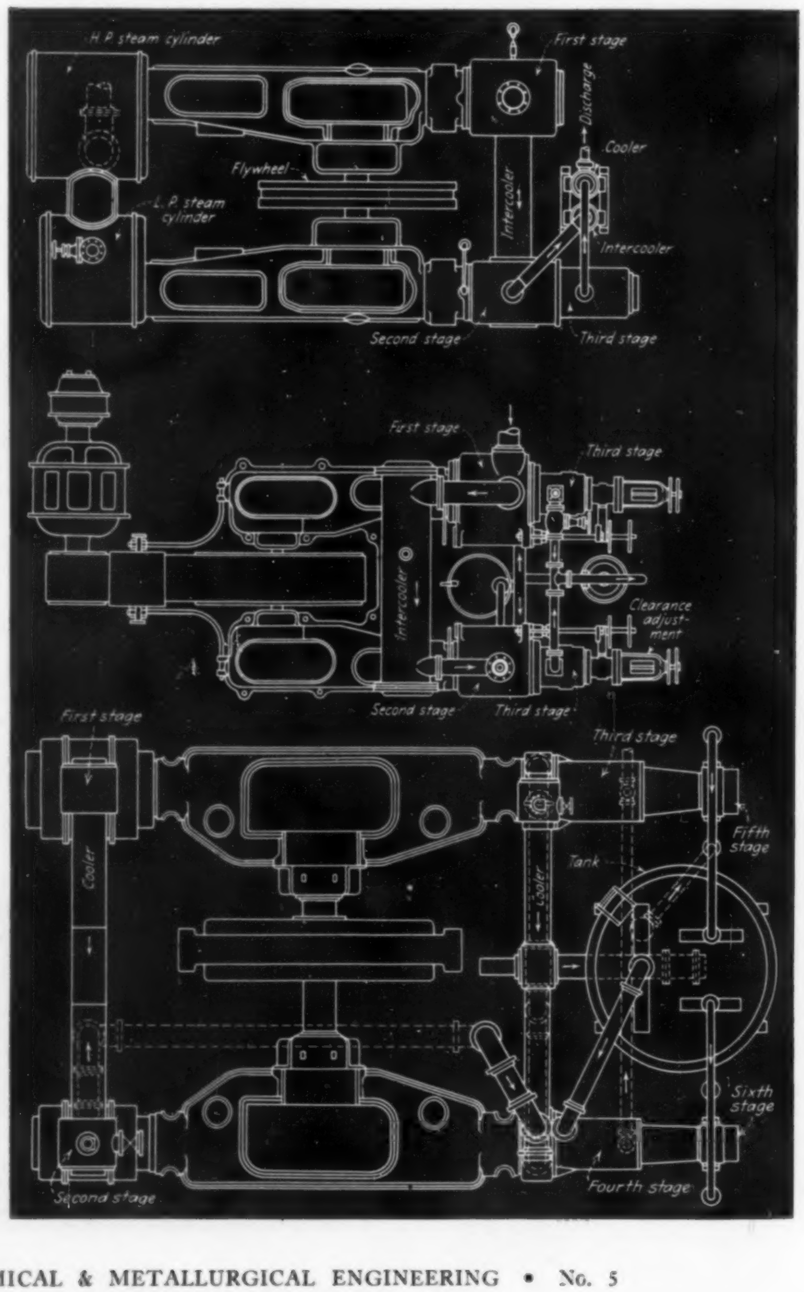
Intercoolers and aftercoolers require special consideration. Coolers following the first and second stages are usually of the shell-and-tube type, and the gas is circulated around the tubes carrying the cooling fluid. Intercoolers above the second stage and the aftercooler are designed for passing the gas through tubes and circulating the cooling fluid around them. In small and intermediate sizes, past common practice has been to use a helical coil in pot-type construction. The trend in large units of recent design is to use shell-and-tube type coolers throughout. In addition to intercoolers, traps for collecting oil and moisture dropped out by the coolers are provided after each stage. Each is equipped with a safety valve. For pressures above 1,500 lb., traps are usually forged steel bottles and valves are of special materials.

Capacity regulation of electrically driven machines is generally obtained by providing hand-operated clearance pockets on the cylinders of the first two or three stages. These provide means for reducing the gas compressed by as much as 15 to 30 per cent. Capacity regulation of steam-driven units can be obtained merely by varying the speed. On all machines, provision is made for unloading all cylinders for starting. In an accompanying illustration the first and second-stage cylinders are equipped with hand-operated clearance pockets. This is a six-stage, 4-cornered, 27-in stroke, 4,500 lb. discharge compressor used in the manufacture of synthetic ammonia. The compressor is direct-driven at 120 r.p.m. by a 2,250-hp. synchronous motor centrally located between the frames. The first- and second-stage cylinders are double-acting; all others are single-acting.

The foregoing discussion pertains essentially to compressors working through a pressure range of from near zero gage to the ultimate discharge pressure. In addition to these, there are in service many boosters or circulators that work only in the higher pressure ranges. Such units may be designed for any number of stages from one to four, depending upon the size of the compressor, the pressure range, and the ratio of compression required or that may be desired.

An article of this length is necessarily limited to generalities and many of the foregoing statements should be interpreted in that light.

Top—Three-stage, duplex, steam-driven compressor. Center—Three-stage compressor for solid carbon dioxide. Bottom—Six-stage compressor for production of synthetic ammonia



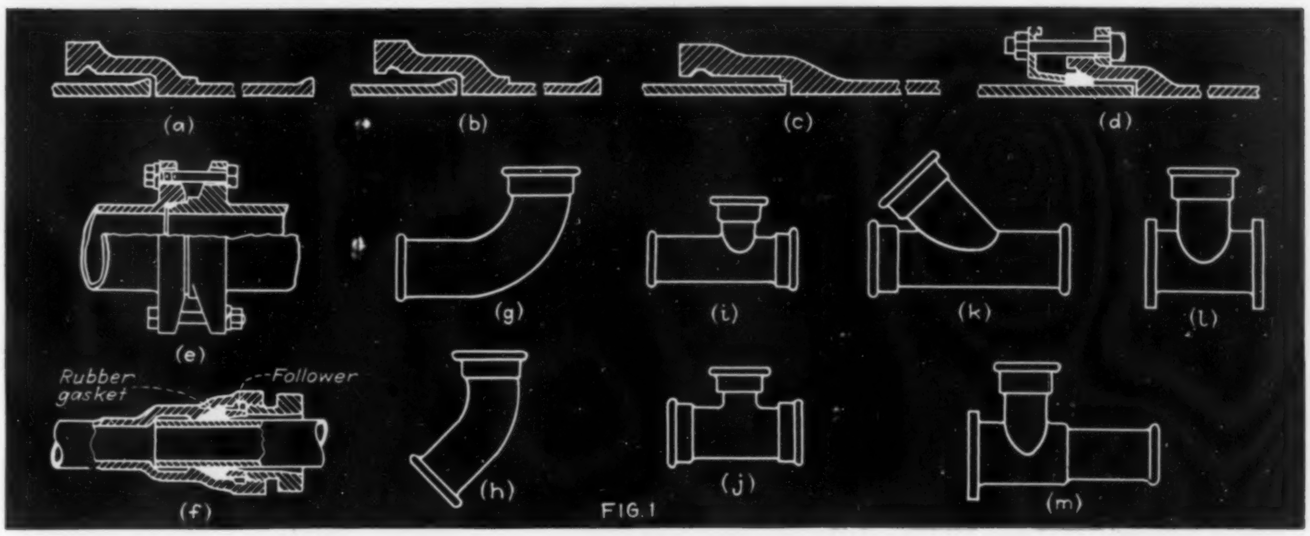


Fig. 1—(a)-(f), Types of joint for cast iron pipe; (g)-(m), fittings for cast iron pipe

PIPE AND FITTINGS

EDITORIAL STAFF

OWING to the fact that there is not often a cheaper or more convenient way of moving fluid process materials about the plant than by flowing them through conduits of one sort or another, pipe in its numerous variations fills an indispensable place in the process industries. Taking the group as a whole, despite the great variety of problems, by far the great bulk of the piping is of standard character, constructed from cast iron, mild steel or wrought iron. If in what follows the standard constructions and materials appear to have received undue emphasis, it will be because of this fact.

Ferrous Piping

Iron and its alloys cover the great majority of piping requirements, a fortunate fact, since the simpler iron alloys are the cheapest of metals. Among the alloys other than cast iron, mild steel pipe which is commonly referred to as "iron," takes care of the majority of requirements. Such pipe may be obtained either "black" or galvanized. Pipe of the same general characteristics is also made from wrought iron, a material of somewhat higher cost which is generally considered to be superior to steel in corrosion resistance. Better corrosion resistance than that of mild steel is also obtained by adding small percentages of alloying agents such as copper or copper and molybdenum, while larger percentages of such alloying elements as chromium or chromium and nickel, or tungsten, impart still greater corrosion resistance and better mechanical properties.

Cast iron is used to a large extent for water, drainage and fuel gas piping, as well as certain sorts of process work where its combination of superior corrosion resistance and low cost is attractive. Still better corrosion resistance is possessed by certain alloy cast irons often used for pipe, among which may be mentioned the nickel- and high-silicon-iron cast irons. An extensive tabulation of both ferrous and non-ferrous alloys appeared in the October, 1936, issue of *Chem. & Met.*, with information listed in most cases showing whether the alloy can be fabricated in the form of pipe.

Pipe Fabrication—The methods used in manufacturing steel pipe (as well as pipe of other iron alloys that do not require casting) depend largely on the size and to some extent on the purpose for which the pipe is intended. In the butt welding method, the steel is cut into strips of "skelp" of the proper width and forced through a die at welding heat so as to form a cylinder and at the same time weld together the abutting edges. This method is used for most pipe produced in smaller sizes, but does not give as reliable a joint as is obtained by the methods to be mentioned below. A patented modification of this method, which is said to give a weld of efficiency equal to that of the pipe, forms the cold skelp into a cylinder by passing it through a series of dies after which the abutting edges are electrically welded using the high resistance of the unwelded joint to produce heat within the metal itself.

In the next range of size, the lap welding method is employed. In this case, the white hot skelp is die-formed into a cylinder with lapping edges and the edges welded together by pressure between a mandrel within the pipe and a roll outside. Still larger pipe is produced by the somewhat similar method of hammer welding. Here a plate of proper width and thickness is cold rolled to produce a cylinder with lapping edges, the lap is heated and the edges welded by hammering against the mandrel. Alternatively, the plate, rolled to have the edges abutting, is sometimes joined by fusion welding, using either the electric arc or torch.

Seamless Construction

Three methods are employed for producing seamless pipe and tubing. Owing to the lack of weld and the refinement of grain produced during fabrication, such pipe is somewhat stronger than welded pipe. Two of the methods are drawing processes while the third makes use of forging. This last is used to meet the most severe pressure and temperature conditions, requiring the boring and machining of a solid forging. Of the drawing processes, the first, used in the smaller sizes, consists in forcing a white hot billet of steel against a piercing mandrel by means of rolls. The pierced billet, while still hot, is then passed through a series of reducing, sizing and finishing rolls until the desired product is obtained. For larger seamless pipe, the cupping process is used. Here a circular sheet of low-carbon steel is heated, punched into the form of a shallow cup, and the cup drawn

through a series of dies until the desired size is reached—subsequent finish depending on the use of the pipe.

Steel pipe is also made by rolling skelp into a spiral and riveting or occasionally welding the overlapping edges. Such pipe has the advantage of lightness and is produced for working pressures from low to moderate.

Pipe Sizes—In the size range from ⅛ to 12 in., steel pipe (as well as wrought iron pipe) is designated by its nominal inside diameter. Standard pipe is made by the butt-weld process in sizes from ⅛ to 3 in. and by lap welding in sizes from 2 to 12 in. Two heavier grades known as Extra Strong and Double Extra Strong are also made in this size range. Extra Strong pipe is produced in sizes from ⅛ to 3 in. by butt welding and from 2 to 12 in. by lap welding. Double Extra Strong pipe is butt welded in sizes from ½ to 2½ in. and lap welded from 2 to 8 in. In all three weights the outside diameter is the same for pipe of corresponding nominal size, in order that the same threading tools may be used.

Pipe of 14 in. size and larger is specified by its outside diameter (O.D.) and wall thickness. Lap welded, it is made in diameters to 24 in. while sizes from 22 to 96 in. are produced by the hammer and fusion welding processes.

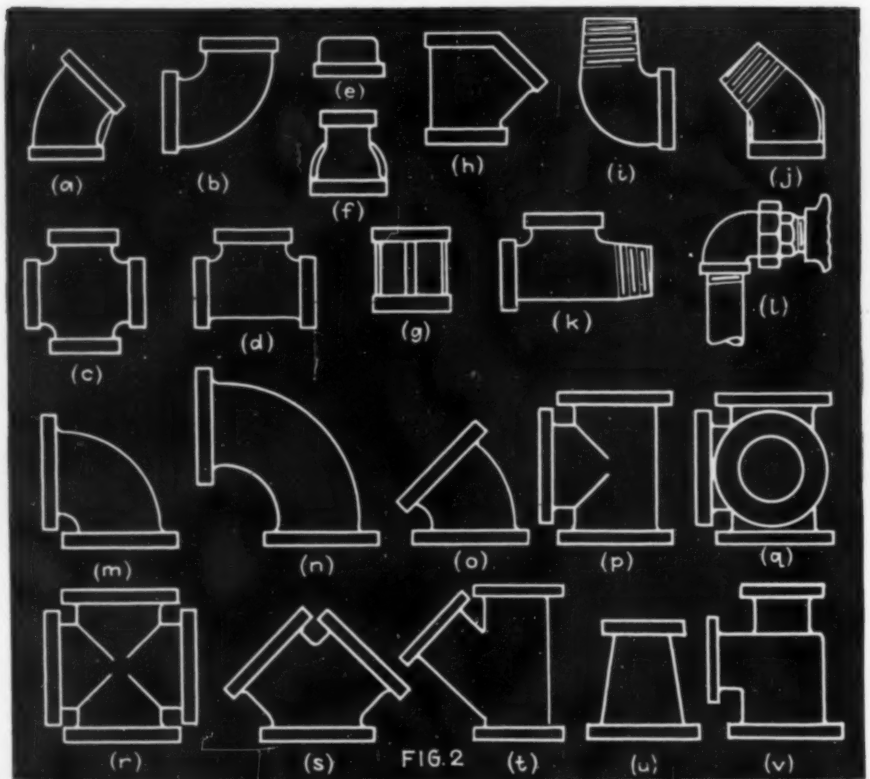
Seamless drawn products are designated by two different systems. (*a*) Seamless *pipe* having the same external diameter as the corresponding iron (i.e., steel) pipe size, is specified by its nominal internal diameter (i.p.s. = iron pipe size) and by its working pressure rating in sizes to 12 in.; and by working pressure rating and outside diameter in sizes from 14 to 24 in. (*b*) Seamless *tubing* for mechanical purposes and for boiler tubes is produced in sizes, designated by actual outside diameter and wall thickness. Standard sizes range from ½ in. O.D., or smaller in the case of some manufacturers, to 16 in., with a considerable range of wall thicknesses available in each size.

Spiral riveted pipe is regularly made in diameters from 3 to 42 in. O.D., while the spiral welded product is produced in a range of sizes from 6⅝ to 24 in O.D.

Working Pressure—The safe working pressure of steel pipe depends to a marked degree on the temperature of operation. Table I lists a résumé of the recommendations of the Power Piping Society for service conditions of standard and extra strong butt- and lap-welded steel pipe at moderate temperatures. At atmospheric temperature, Barlow's formula for bursting pressure gives an indication of suitable working pressure. This formula is $P = 2ft/D$, where P is the bursting pressure in lb. per sq.in., f is the fiber stress of the pipe material, taken at 40,000 lb. per sq.in. for butt welded pipe and 50,000 lb. for lap welded pipe, t is the wall thickness in inches and D is the outside diameter in inches. Working pressures 15 to 25 per cent of the calculated bursting pressure are usually considered safe.

For pipe to operate at temperatures in the neighborhood of 750 deg. F., A.S.T.M. Specification A 106-33 T covers six pressure ranges, listing pipe sizes from ½ to 24 inches and specifying the type of steel and the wall thickness. The ranges include 250 lb. for lap-welded pipe; 300 lb. for seamless pipe, 400 lb. for lap welded and seamless pipe; and 600, 900 and 1,500 lb. for seamless pipe. Some grades are of the same thickness as the standard or Extra Strong iron pipe. Table II, based on the A.S.T.M. Specification, gives an excellent indication of the effect of temperature on the safe working pressure, showing that lower temperatures than 750 deg. F. permit higher pressures than rated, and vice versa.

Cast Iron—Cast iron pipe is extensively used for the handling of water, gas and sewerage, as well as process fluids. It is made by two different processes: by ordinary casting in sand molds and by centrifugal casting in rotating metal molds. The latter process gives a denser product of considerably greater strength, particularly suited to the transmission of high pressure gas owing to the absence of blow holes and impurities. Pipe of the first type (sand cast) is made in sizes ranging from 3 to 84



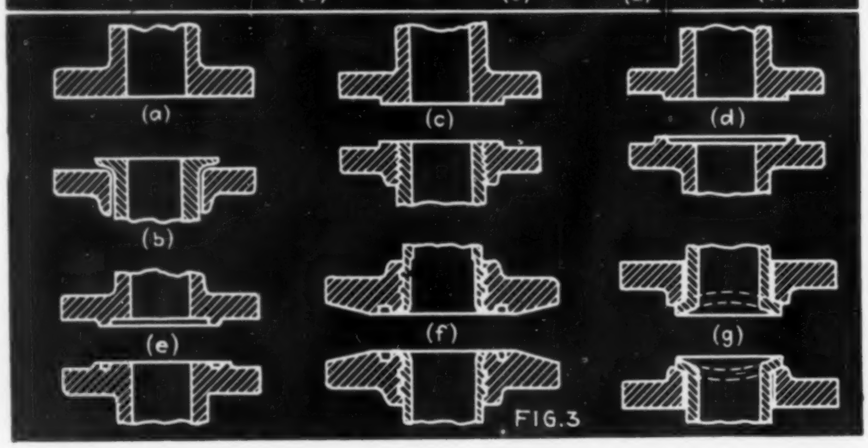


Fig. 2—(*a*)-(*l*), Typical screwed fittings; (*m*)-(*v*), typical cast iron flanged fittings

Fig. 3—Several types of flanged joint for piping

Table I—Steel Pipe Service at Moderate Temperatures

(Based on recommendations of the Power Piping Society)

Class of Service:

1. Saturated steam, 0-160 lb. ga.
   Boiler feed to 125 lb. < 250 deg. F.
   Service water to 175 lb. ga.
   Exhaust steam
2. Saturated steam, 160-250 lb.
3. Boiler feed, 125-325 lb. > 250 deg. F.

Type of Pipe, Size, Service

Standard weight butt weld:
Sizes ½ to 3 in., used in (1)

Standard weight lap weld:
Sizes 3 to 12 in., used in (1)
Sizes 2 to 12 in., used in (2)

Extra Strong butt weld:
Sizes ½ to 1½ in., used in (2) and (3)

Extra Strong lap weld:
Sizes 2 to 12 in., used in (3)

Table II—Safe Working Pressures for Pipe Rated at 750 deg. F.

(Service pressures for steam, based on A. S. T. M. Specification A-106-33T)

Working temperature, deg. F.	500	550	600	650	700	750*	800	850
Safe pressures	310	300	290	280	260	250	200	165
	370	360	350	330	315	300	250	200
	500	480	460	440	420	400	325	270
	720	720	700	670	630	600	500	400
	1,080	1,080	1,040	1,000	950	900	750	600
	1,800	1,800	1,740	1,660	1,580	1,500	1,250	1,000

* Rated temperature.

in. nominal inside diameter and, depending on size, in up to eight pressure classifications, ranging from 100 to 800 ft. head (43 to 347 lb. gage). Centrifugally cast pipe is produced in sizes from 4 to 20 in. nominal inside diameter and in thicknesses for working pressures from 50 to 250 lb.

Pipe intended specifically for water has been specified completely by the American Water Works Association, while similar specifications for gas pipe have been promulgated by the American Gas Association.

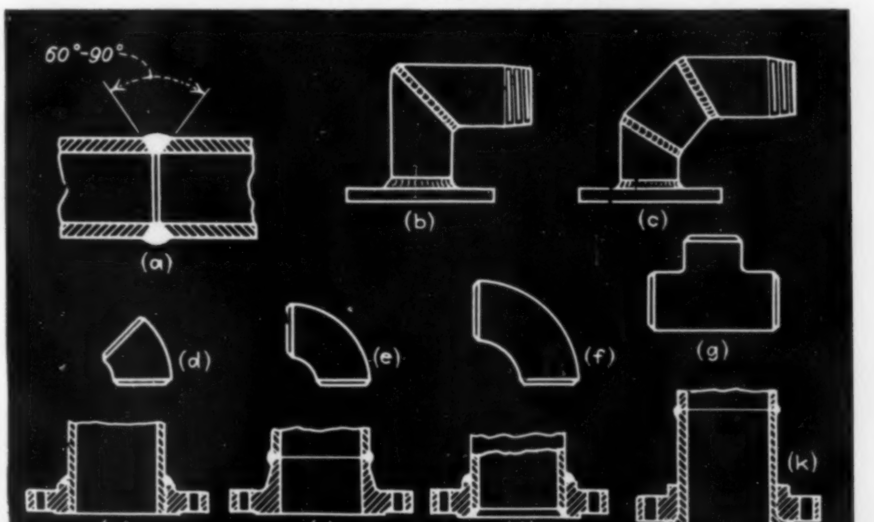
Cast iron soil pipe, intended for plumbing drainage work is available in sizes ranging from 2 to 6 in. It is considerably lighter than cast iron water or gas pipe.

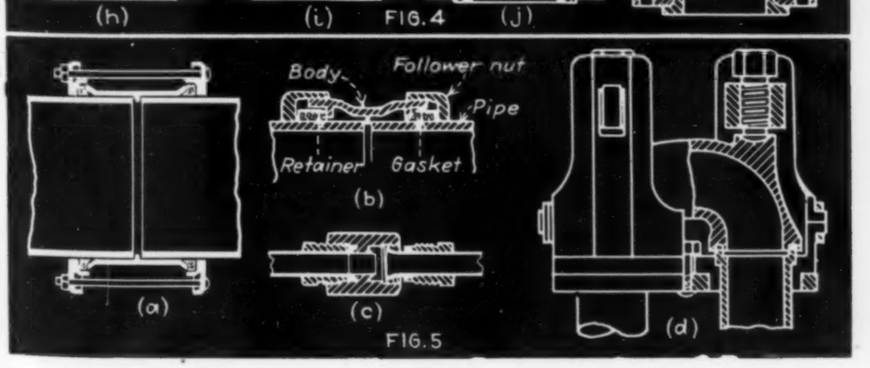
A special nickel alloy cast iron that has been employed for pipe in the smaller sizes by the Walworth Co. is capable of being threaded with ordinary threading tools.

Alloy Pipe—Most large pipe manufacturers, especially those making seamless products, are now able to supply pipe in both O.D. and iron pipe sizes, made from a number of chrome irons and nickel-chromium steels. Those alloys which cannot be worked by the usual fabricating methods can be had in the form of pipe castings, made by both the sand cast and centrifugal processes.

Fig. 4—Examples of welded ells, weld fittings and methods of attaching pipe flanges by welding

Fig. 5—Special couplings and fittings





Non-Ferrous Pipe

Several of the non-ferrous metals and alloys are represented in standard lines of pipe and tubing. Aluminum and a number of its alloys ranging in strength upward to that of carbon steel pipe are produced in a considerable number of sizes and wall thicknesses in addition to iron pipe size. This last is the most used specification. In this designation, both standard weight and Extra Strong pipe are available, the nominal sizes ranging from ⅛ to 8 in. At 75 deg. F. the safe working pressure for 1-in. i.p.s. standard pipe of 2SO aluminum is 667 lb. per sq.in. Higher temperature decreases this sharply, a fact which must be considered in using this material. For example, the safe pressure falls to 80 per cent at 200 deg. F. and 30 per cent at 500 deg. With the other alloys available, the cold working pressure is higher, but decreases with temperature rise in about the same proportion.

Copper and its alloys are important pipe materials. Copper used for pipe is generally the deoxidized electrolytic product, having a tensile strength of at least 30,000 to 40,000 lb. after annealing, depending on size. Brass is also used to a considerable extent, although its corrosion resistance is not as good, in general, as that of copper. Its price is somewhat less and it threads more readily than copper. Brass for pipe generally contains about 65 per cent copper, smaller percentages of lead and iron and the remainder, zinc. Its tensile strength is of the order of 50,000 lb. in the semi-hard condition. Both copper and brass are produced in standard and Extra Strong iron pipe sizes, ranging from ⅛ to 10 in., as well as in a large number of O.D. sizes and wall thicknesses.

Copper alloyed with nickel (Monel metal) and also nickel pipe are available for use where these materials are indicated.

Lead Pipe—Lead is one of the most important materials used for special process piping, owing to its resistance to a variety of acid solutions. Its ease of use is to some extent offset by low strength and a tendency to creep, but where these factors would adversely affect its use, lead can be supplied as a lining, homogeneously bonded within a steel pipe. Standard, unreinforced, chemical lead pipe is designated by actual internal diameter and a letter indicating wall thickness. It is produced

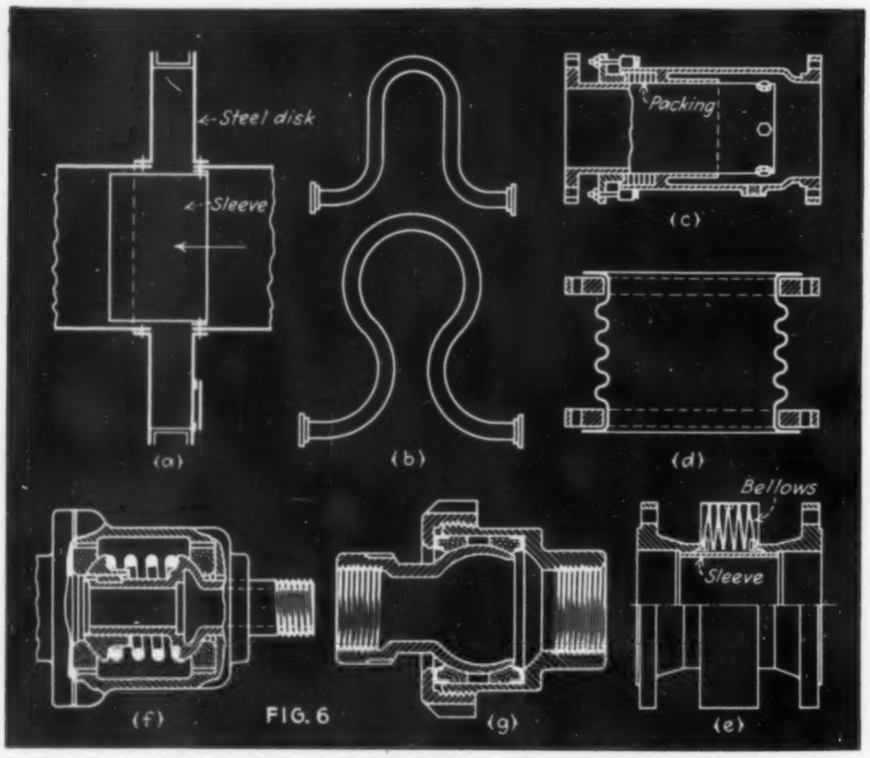


Fig. 6—(a)-(e), Typical expansion joints; (f)-(g), rotary and flexible joints

by extrusion in inside diameters ranging from $\frac{3}{8}$ to 2 in. or larger. In most sizes, seven or eight wall thicknesses are available. Safe working pressure is generally determined by the Barlow formula (see *Steel Pipe,* above) using a fiber stress of 2,300 lb. per sq.in. and a factor of safety of 8.

Among the other special materials also used for pipe is tantalum which has been used as a lining. Silver, gold, gold-filled and block tin pipe are all available on the market.

Non-Metallic Pipe

Cement pipe appears in several forms. Large cylindrical sections of reinforced concrete are used in water mains and for sewerage, either with bell and spigot joints or with a special flush lock joint. Steel pipe, cement lined by a centrifugal process, finds application particularly in water supply work by reason of its long continued freedom from tuberculation or incrustation. Transite pipe is a composition of portland cement and asbestos which is highly resistant to corrosive waters and soil acids, as well as dilute industrial materials. It is produced in a wide variety of diameters, together with suitable fittings.

Ceramic pipe fills an important place where particularly severe acid conditions must be met. Ordinary salt-glazed terra cotta, pipe is made in many sizes, bell and spigot joints being standard. The resistance of this material suffices for ordinary sewerage, but for most chemical plant requirements, chemical stoneware is necessary. Chemical stoneware pipe may be obtained to user's specifications in a wide range of sizes and weights, and made from compositions covering an extended range of physical properties. Use of the de-airing process in extruding tubular stoneware products has permitted thinner sections and much better heat transfer in the case of stoneware heating and cooling coils.

Glass is being used to a considerable extent in chemical plant work. Glass tubing, joined with sleeves of rubber tubing, is a very old pipe material for hydrochloric acid plants. Recently industrial glass pipe in a considerable range of sizes has been developed and marketed by the Corning Glass Works. Glass-lined (enameled) steel pipe is frequently used in conjunction with enameled equipment. Both pipe and fittings are produced by the Pfaudler Co.

Resinoids of phenol formaldehyde resin and asbestos are molded into corrosion resisting pipe and fittings by the Haveg Corp. Haveg pipe for liquids is regularly available in the internal diameters from 2 to 12 in. for pressures to 25 lb. ga. and temperatures to 265 deg. F. A lighter grade for fume ducts working at pressures not over a few inches w.g. comes in sizes from 2 to 30 in.

Rubber is used in several ways in conveying corrosive fluids. Acid hose, built with fabric reinforcement for pressure service and metal reinforcement for suction service, is convenient when flexibility is necessary and sometimes essential owing to the nature of the fluid. Both hard and soft rubber linings are used in steel pipe for service where strength rather than flexibility is needed. Hard rubber pipe and all essential types of fittings may also be secured. The compounding of the rubber can be carried out to suit a variety of conditions. For applications where rubber itself is not suitable, linings of Neoprene or Thiokol, or of rubber compounded with these materials, sometimes are required.

One of the oldest of pipe materials, wood, is still used for certain sorts of service, particularly where contamination and discoloration are to be avoided. In smaller diameters wood-lined metal pipe is made in lengths up to 24 ft. for service at pressures as high as 200 lb. Such woods as Douglas fir, cypress and yellow pine are used. Simple wood-lined fittings are also made. Large flows of water, such as in municipal water supply, are handled to a considerable extent in wood stave pipe of large diameter.

Pipe Joints

In general, joints are required for two purposes: (1) for joining continuous lengths of pipe, and (2), for the insertion in pipe lines of fittings which will permit a change of direction or diameter, the addition of a branch or side connection, or will take charge of thermal dimensional changes in the pipe.

Cast Iron Pipe—Most cast-iron pipe employs one or another variety of bell and spigot joint, a number of types of which are shown in Fig. 1. That at *a* is the standard for sand-cast water piping and at *b*, for sand-cast gas pipe. Sketch *c* shows the type used for standard centrifugally cast water pipe while sketch *d* shows the special Anthony high-pressure bell, a packed joint sometimes used with centrifugally cast gas pipe. A high-pressure joint, the Dual-Lok, developed by the Central Foundry Co. is shown at (*e*). The seal is formed by both a gasket and a metal-to-metal joint. For smaller pipe the McWane Glantite joint, shown at (*f*), gives a tight seal and permits expansion and contraction.

Bell and spigot joints are generally made up by pouring in lead and calking it, or with special cements such as those with a sulphur base. A bell and spigot joint gives sufficient flexibility to the line for ordinary purposes and also permits the small amount of slip necessary to take care of thermal changes. Cast-iron pipe is also made with flanged ends for assembling with a gasket and with plain ends for use with various sorts of proprietary coupling.

A number of sorts of fittings are available for cast iron pipe. Several of the types used in water mains and specified by the American Water Works Association appear in Fig. 1, sketches

g to m inclusive. The first three of these have both bell and spigot ends. At j is a tee with spigot ends only The tee at l has one bell and two flanged ends while the reducing tee at m has ends of three different sorts. Various combinations are available, as well as certain other fittings.

Steel Pipe Joints and Fittings

Pipe fabricated from the ductile metals and alloys, both welded and seamless, is joined either with screwed or flanged joints and fittings. What is said here in regard to steel pipe applies also to wrought iron, steel alloys, copper, brass, Monel and nickel, aluminum and similar materials.

Although screwed fittings are available in sizes ranging from the smallest to as large as 24 in. in certain classes, screwed fittings are not ordinarily used above moderate pressures in sizes greater than 2 or 3 in. Even in the smaller sizes, a high grade of workmanship is required in producing a tight screwed joint without reliance on a sealing compound and the problem becomes more difficult as the size increases. Furthermore, threading obviously produces some weakening of the pipe.

Screwed Fittings—Screwed fittings are made in cast iron, malleable iron, cast and forged steel. Cast and malleable iron fittings are regularly available for 125 or 150 lb. steam pressure, depending on the manufacturer, and in heavier designs for 250 or 300 lb. steam pressure at temperatures to 550 deg. F. Such fittings can be used at considerably higher pressures for water, oil or gas at atmospheric temperature. Malleable iron hydraulic fittings are rated at 800 to 2,000 lb. working pressure, depending on size. Cast steel screwed fittings are rated at pressures from 1,000 to 9,000 lb. for cold water, oil and gas. Fig. 2 shows several of the simpler varieties of screwed cast-iron fitting. These are as follows: (a) 45 deg. screwed ell; (b) 90 deg. ell; (c) cross; (d) tee; (e) cap; (f) reducer; (g) coupling; (h) Y (actually a lateral); (i) 90 deg. street ell; (j) 45 deg. street ell; (k) service tee; and (l) union ell with both male and female ends. There are a great many other varieties of screwed fittings. Unions, for example, are made with various kinds of seal, including several sorts of ground joint, and gasket types. The union ell shown is one of a number of sorts of union fitting which greatly simplify piping installation.

Cast iron flanged fittings are made in ratings of 25, 125 and 250 lb. while the American standard cast iron hydraulic fittings are rated at 800 lb. Standard cast steel flange fittings are produced in six classifications for 150, 300, 400, 600, 900 and 1,500 lb. pressure at 750 deg. F. The pressure rating for cast steel fittings varies with the temperature in much the same manner

Cost Estimates on Piping

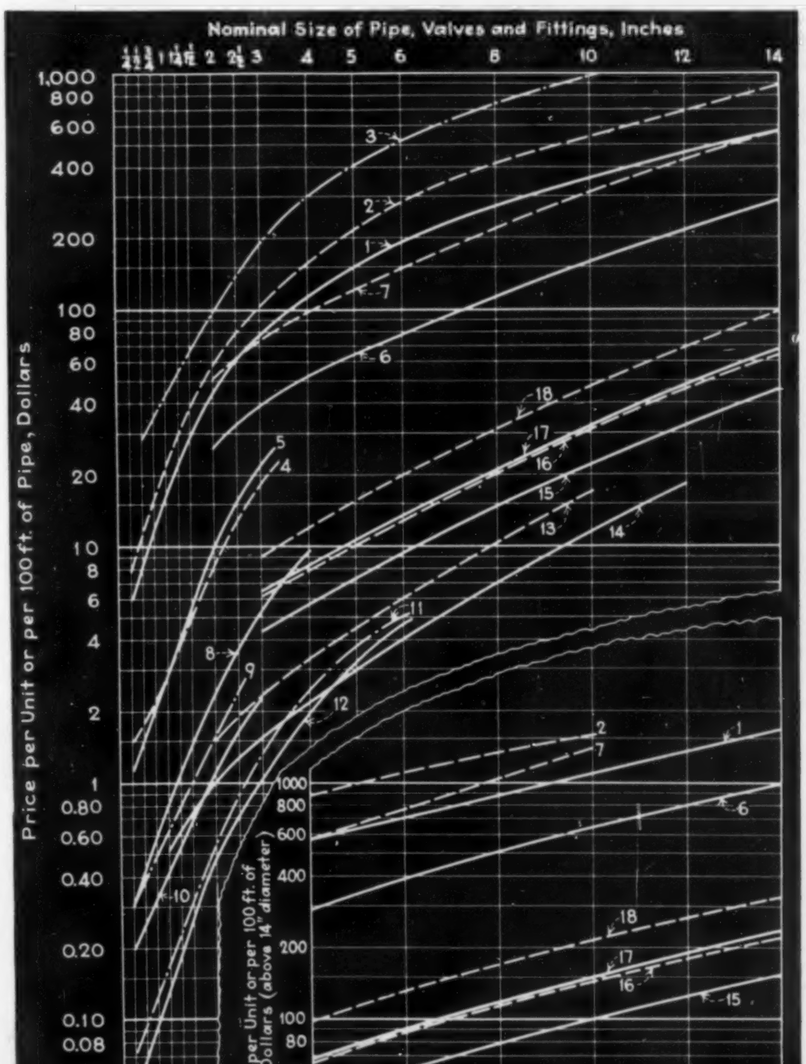
By C. E. MILLER

THE ACCOMPANYING CHART has been found useful for estimating costs of piping installations in cases where no great accuracy is required. By plotting manufacturers' list prices on pipe and fittings against nominal pipe size, a set of fairly smooth curves has been obtained which offers a simple and quick means of preparing preliminary cost estimates.

The prices given in the chart are subject to discounts which vary with the market price of raw materials, manufacturing costs, quantity purchases, demand and other factors. Hence, estimates based on the chart will in general tend to be somewhat higher than actual quotations for the material. For simple installations, the material cost taken from the chart may approximate the installed cost of the piping.

Key List for Chart

1. Black iron pipe std., 700-800 lb. test pressure.
2. Black iron pipe, extra heavy, 1,000-1,100 lb. test pressure
3. Black iron pipe, double extra heavy
4. Brass gate valve, threaded, 125 lb. std.
5. Brass globe valve, threaded, 125 lb. std.
6. Gate valve, flanged, 150-200 lb. std., brass trimmed or all iron
7. Gate valve, flanged, 500 lb. std., brass trimmed or all iron
8. Malleable iron union, threaded, 150 and 300 lb.
9. Malleable iron tee, threaded, 300 lb.
10. Malleable iron elbow, threaded, 300 lb.
11. Malleable iron tee, threaded, 125 lt. std.
12. Malleable iron elbow, threaded, 125 lb. std.
13. Cast iron union, flanged, 250 lb. std.
14. Cast iron union, flanged, 125 lb. std.
15. Cast iron union, flanged, 125 lb.
16. Cast iron tee, flanged, 125 lb.
17. Cast iron elbow, flanged, 250 lb.
18. Cast iron tee, flanged, 250 lb.



as for seamless pipe, as shown in Table II. Forged steel flanged fittings have ratings of 600, 900 and 1,500 lb. at 900 deg. F.

Sketches *m* to *v* of Fig. 2 show a number of typical cast iron flanged fittings including: (*m*) ell; (*n*) long radius ell; (*o*) 45 deg. ell; (*p*) tee; (*q*) side outlet tee; (*r*) cross; (*s*) true Y; (*t*) lateral; (*u*) reducer; (*v*) reducing tee.

Types of Flange

Flanges are produced from cast iron, cast steel and forged steel and are attached to pipe in a number of different fashions. Furthermore, there is considerable variation in the type of flange face used and only those most important in process plants can be touched on here.

Flanges carry the same pressure ratings as flanged fittings. For lower pressures a common method of attaching the flange to the pipe is to use a screwed joint. Screwed joints are assembled either by cutting a short thread or by using a long thread and machining the face of the assembled joint. Fig. 4*h* shows a common method of making a screwed flange more secure by welding. For higher pressures, shop attachment of the flange is generally practiced and the pipe may either be rolled into the flange or turned over to form one of a number of varieties of lap joint as shown in Fig. 3*b*. The square lap now generally used may be upset to such an extent that it is thicker than the original pipe and it is now common practice to apply any special flange facing desired to the lap rather than to the flange. Flanges are also attached to the pipe by various methods employing welding, as shown in Fig. 4*h* to *k*.

Some of the more common types of flange facing appear in Fig. 3. At (*a*) is the plain face used for relatively low pressures. At (*b*) is the improved Van Stone joint or square lap. (*c*) shows the raised face flange which with various facings is used to a large extent for the higher pressures. The male and female joint appears at (*d*) and the tongue and groove joint at (*e*). For some high pressure work, the ring type of joint shown at (*f*) is used while the flared or Texas joint shown at (*g*) is of interest in refinery service. This joint uses a metal toroidal ring for the gasket. A type of flanged joint (not shown) now considerably used in high temperature power plant work is the patented Sarlun joint in which the outside periphery of the lap is turned down to form a narrow edge which is sealed by welding.

Welded Joints

Fusion welding has reached an extremely important place in process and power plant piping. For joining lengths of pipe, the butt weld using either a 60 or 90 deg. scarf (with or without reinforcement) is commonly employed. This is shown in Fig. 4*a*. Two simple methods of fabricating ells appear in (*b*) and (*c*). Several makes of weld fitting are now on the market, including a number of types other than those shown in sketches (*d*), (*e*), (*f*) and (*g*). Such fittings are generally so formed that there is a uniform thickness of metal throughout.

Four important methods for the attachment of flanges by welding are shown in Fig. 4*h* to *k*. The screwed and welded flange at (*h*) has already been mentioned. Special weld flanges such as that shown at (*i*) are now available. A satisfactory method using a slip flange welded at two points as in (*j*) give satisfactory results. The method of (*k*), making use of a loose flange and a welding stub to give a lap joint, has a number of advantages, including that of easy alignment of the bolt holes.

Gaskets

It is possible to produce joints so highly finished that no gasket is required, but in most cases the use of a gasket is a decided economy. For the average joint, the two faces can be given a lathe finish and supplied with a gasket of softer material which creates a seal by adjusting itself to the slight variations in the surface. Rubber, asbestos and vulcanized fiber are some of the more important non-metallic gasket materials. Lead, copper, soft steel or pure iron, Monel metal, silver and sometimes alloy steels are gasket materials used for high pressures or severely corrosive solutions. The choice and proper design of gaskets are often difficult. The special requirements of the chemical plant have been well covered by Perry (*Chem. & Met.*, April, 1934 p. 194 f.f.).

In addition to the types of joint already covered, there are a number of special varieties used with drawn and welded types of pipe. Fig. 5*a* shows the Dresser coupling for large pipe, a type of joint giving considerable flexibility, and slipping sufficiently to take care of thermal expansion. It is used to a large extent in large diameter pipe for gas.

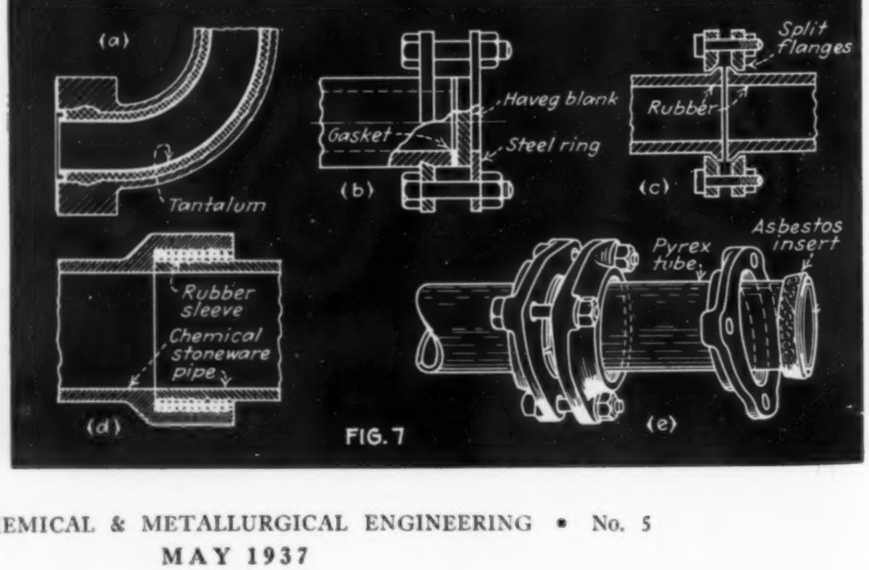
Another type of Dresser coupling for small pipes which also is a form of packed joint appears at (*b*). Small copper and brass pipe is often joined by compression fittings of the type shown at (*c*). For somewhat larger copper and brass pipe, the sweated or solder type fitting has recently become important. At (*d*) is shown a special demountable return bend designed by the Stockham Pipe and Fittings Co. and used in pipe stills.

Expansion Joints

Unless compensated for, temperature changes can set up dangerous stresses in a pipe line and may under severe circumstances damage either the pipe or the equipment. Even in cast iron water mains the summer-to-winter temperature change is generally sufficient to require some provision for expansion. In the ordinary bell and spigot pipe, the leaded joint does provide for this expansion and additional protection is not required. The special cast iron joints shown in Fig. 1*d* and *f* provide for expansion. The same is true of the special iron pipe couplings shown in Fig. 5*a* and *b*.

A method frequently used to take care of expansion in large low-pressure gas and vapor piping appears in Fig. 6*a*. This plate expansion joint which can be fabricated in any welding shop is successful for considerable temperature changes at low pressures. In higher pressure piping which may operate at a considerable temperature, the use of

Fig. 7—Joints used in special metallic and non-metallic construction



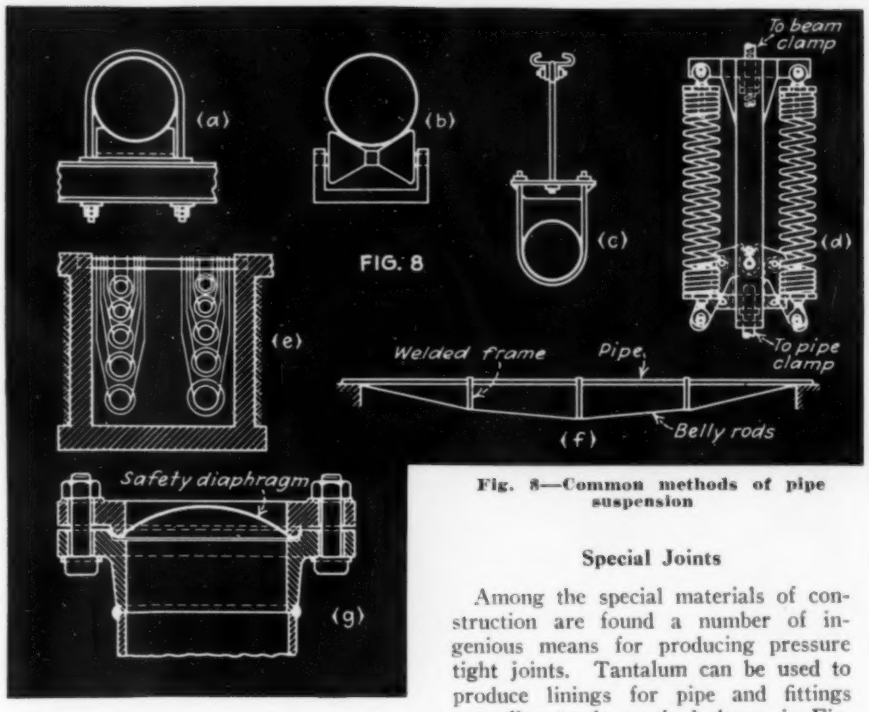


Fig. 8—Common methods of pipe suspension

pipe bends as in (*b*) is generally considered most satisfactory. These bends may be joined to the line either by flanges or by welding. A method frequently used in steam plant work is to use a packed sliding sleeve type of joint such as the Yarnall-Waring joint shown in (*c*). Such equipment is made with both a single and a double slip-joint type of construction.

For low-pressure work at not over 25 lb. gage, the simple corrugated copper sleeve shown in (*d*) is often useful. A type of reinforcement is used on corrugated copper joints on pressures up to 125 lb. gage.

A recent development of the Foster-Wheeler Corp. is the bellows expansion joint shown at (*e*). By increasing the number of diaphragms used in the bellows, any desired amount of expansion can be handled. These joints can take care of a certain amount of misalignment.

Flexible Joints

Flexibility, or the ability to swivel, is sometimes necessary in piping. The joint shown at (*f*), made by the Johnson Corp., is a rotating pressure joint useful in connecting rotating equipment into a pressure fluid handling system. The joint at (*g*) is one of several Barco joints, a design useful for lines of considerable size. It not only permits angular movement, but can also be swiveled through an angle of 360 deg. For the lower pressures it is sometimes possible to provide flexibility and take care of expansion as well, by means of an offset constructed of ordinary pipe and screwed fittings.

Special Joints

Among the special materials of construction are found a number of ingenious means for producing pressure tight joints. Tantalum can be used to produce linings for pipe and fittings according to the method shown in Fig. 7*a*. Note that the lining is carried over the surface of the flange. The sketch at (*b*) shows the special type of joint used with Haveg pipe and fittings. A cast iron split collar of special design is employed, seated in a groove cut in the pipe. A common method of joining acid hose is to push it over a nipple and attach clamps. However, this method sometimes damages the hose and the method shown in sketch (*c*) is considered superior. Abutting ends of the hose are formed as shown and held together by split flanges. The construction is suitable for 125 lb. working pressure.

Various types of joint are used in stoneware pipe. Often, the ends of the pipe are provided with a projection of some sort for attaching metal flanges and the joint made tight with a gasket. Both screwed and bell and spigot joints are used. A type of joint which has recently come into prominence is the Flexlock joint shown in sketch (*d*). This joint is of the bell and spigot type with a rubber sleeve of special cross section which serves as an effective seal. It is a joint development of B. F. Goodrich Co. and the U. S. Stoneware Co. Recently a type of split ceramic sleeve for use with the regular Flexlock rubber has been announced. A type of joint developed by the Corning Glass Works for use in Pyrex glass pipe appears in sketch (*e*).

The subject of special cements and luting materials for chemical plant use has been covered in considerable detail in the October, 1934, issue of *Chem. & Met.*, p. 537, f.f. For ordinary screwed joints in iron pipe, litharge and glycerine, and white lead, cover most requirements.

Pipe Installation

Proper layout and installation of piping is so broad a theme that it could easily be the subject of a handbook. Most piping in a chemical plant is exposed within the building, supported either by the walls or the building framework. In Fig. 8, sketch (*a*) shows a simple beam clamp for pipe. Piping which must provide for expansion is frequently supported at points between expansion joints by means of a roller such as that shown at (*b*). Piping which can be suspended from a beam as in (*c*) will generally take care of what movement is necessary between expansion joints. For piping operating at extremely high temperatures, spring hangers are sometimes used to give a flexible support yielding with thermal changes. Some of these hangers are relatively simple while others, like the Grinnell hanger shown at (*d*), are so designed as to give a constant support regardless of the amount of flexing of the spring.

Except for drainage, water and gas piping, underground piping in chemical plants is rarely buried since such procedure makes the location of leaks difficult and involves much work in making repairs. Process piping carried underground is customarily installed in trenches, where it is readily available for inspection and repairs. Sketch (*e*) diagrams a simple method of trench installation where a number of pipes of different size are to be installed.

Overhead outdoor piping in smaller sizes can be supported from pipe stanchions. For larger sizes and for multiple piping, towers fabricated of pipe or structural steel are used. A simple form of truss for supporting piping running between buildings is illustrated in sketch (*f*).

Piping and other fluid handling systems require adequate protection against excessive pressures. In the past, safety valves have necessarily been the chief reliance, but with the recent commercial development of safety rupture diaphragms (sketch *g*) by the Black, Sivalls & Bryson Mfg. Co. a protection method which seems always reliable has become available.

No discussion of piping would be complete without some word about identification. Nothing is more confusing than the maze of piping found in the average chemical plant. Various classification schemes have been proposed, generally involving the use of a particular color of paint for each class of material handled. An A.S.M.E. committee has suggested the use of certain distinctive colors painted on the valves, flanges and fittings. Besides color bands on conspicuous parts of the system, it is often good practice to stencil legends on the pipes so that they can be read from points where the operator is most likely to stand.

VALVES AND CONTROL

WITHOUT MEANS for controlling the flow of fluids, chemical plants would have to return to the bucket and stick variety of chemical engineering, for there would be little use in pipe if there were no way to throttle the flow through it. The following 12 pages, therefore, have been given over to discussions of several phases of the valve problem. Valves as such, with a good deal of practical information based on the author's experience, start the section. Devices for manually operating valves at a distance, follow. Then the measurement and control of static and flowing fluids is allotted another five pages, while a brief résumé of fundamentals in automatic valve operation for process coordination completes the section.

Chemical Plant Valves

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PACIFIC COAST EDITOR
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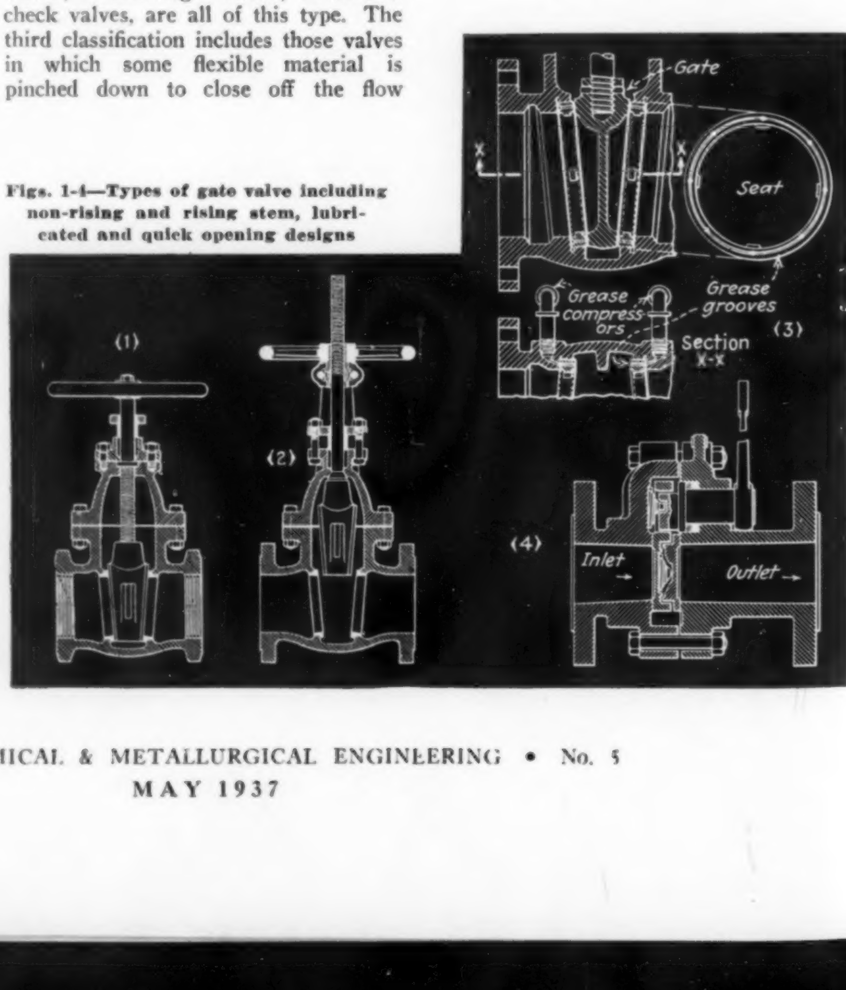
CONTROLLING the flow of fluids is a comparatively complex problem, particularly in the chemical engineering industries where conditions are often so severe that the ingenuity of the valve manufacturer is taxed almost to the limit. For example, proper materials of construction must be chosen with regard to the necessity for handling liquids, gases, and vapors, which may be clean or contain suspended particles, which may be inert or corrosive and which may be at any pressure from near absolute vacuum to many times atmospheric, and at temperatures at any extreme. In many cases the problem is a serious one and the peculiarities of the material often dictate the design.

Obviously, no single type of valve will satisfy all conditions but the variations in valve construction are numerous and the problem of selection is often unduly complicated. As a matter of fact, there are comparatively few fundamental valve types found among those used in process fluids handling, and it will be the object of this article to attempt to simplify selection by a discussion of these general types with some word regarding the limitations and advantages of each. Obviously, no attempt can be made here to discuss the great multitude of specific applications.

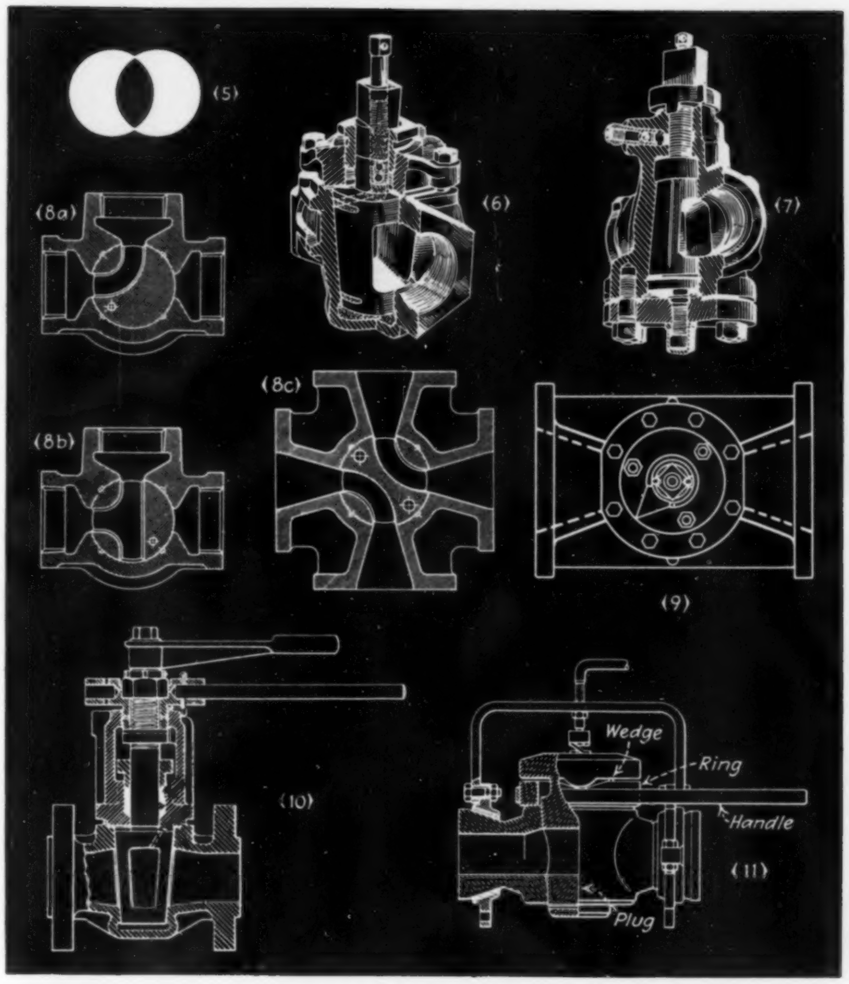
By way of limitation, the discussion will be confined to devices for the manual regulation of fluids flowing in closed conduits. Other articles in this section will deal briefly with the remote manual control of valves, with the measurement and automatic control of static and flowing fluids, and with advances that have recently been made in automatic programming of valve operation for the control of entire processes. The fundamental valve types will, in the main, be described here. These include three major classifications and a number of modifications of each, together with several forms which do not fit readily into a classification.

The first sort of valve is the type in which a sliding member is moved across the flow passage to dam it off. Gate valves and cocks are of this type. Then there is the type of valve in which a plug of some sort is pushed into an opening in the pipe line through which the fluid is flowing, thus shutting it off. Globe valves, plug and needle valves, Y and angle valves, as well as check valves, are all of this type. The third classification includes those valves in which some flexible material is pinched down to close off the flow passage. Finally, among other varieties is the seatless valve employing a sliding piston, balanced valves of several varieties, valves employing special shut-off means such as a rotating damper, and finally valves that make use of a liquid seal for the controlling of gases at pressures near atmospheric.

Practically every material of construction used in the process industries can be had in the form of some sort of valve—often being available in a considerable number of different valve designs. In some cases, however, the limitations of the material make its use possible only in special designs. For example, with materials that are difficult to machine, and can be worked only by casting and grinding, threads and screws must be avoided wherever possible. Such valves tend naturally to be expensive, and simplicity in design has been necessary in bringing their cost to a reasonable point. Cast iron, steel, brass and bronze are, of course, the most commonly employed materials. Also available are the stainless irons



Figs. 1-4—Types of gate valve including non-rising and rising stem, lubricated and quick opening designs



Figs. 5-11—Plug cock variations, illustrating lubricated types, and non-lubricated lifting-plug cocks in metal and chemical stoneware

and steels, high-silicon iron, copper, and nickel alloys, aluminum and other metals, principally lead. Metal linings are often used, lead being the most common. Other materials so used include tantalum, silver and other valuable metals. Many non-metals have been employed successfully including wood, rubber and rubber linings, glass and glass enamel linings, phenol-formaldehyde plastics, and ceramic materials. It is likely that some of the newer synthetic resins will be used extensively in the future to coat valves and pipes and thus insure maximum service per dollar of investment.

Gate Valves

Gate valves operate by moving a barrier across the flow stream. The barrier or gate is guided by a slot on either side of which is ordinarily a removable and replaceable ring-shaped seat. Among the usual types of gate valve are found two important modifications of the gate. In one variety the gate is made in the form of a solid wedge and is forced downward into intimate contact with the seat, forming a tight seal. In the other variety, the gate is composed of two disks which are lowered into the opening and then forced apart against the seats to form the seal. In this second type, opening reverses the closing operation. First the pressure forcing the disks apart is released, then the two are raised out of the flow channel as a unit.

Gate valves are made in sizes ranging from $\frac{1}{8}$ in. to extremely large. There are three principal methods used in raising and lowering the gate. The simplest variety is the type in which the stem is in pivoted engagement with the gate, and slides and turns in the stuffing-box. An inside thread controls the lengthwise motion. The second type (Fig. 1), known as the non-rising stem (N.R.S.), uses a stem which turns but does not slide in the stuffing-box. In this case the threads are placed at the lower end of the stem and its turning causes the gate to screw up or down as the case may be. The fact that there is no lengthwise movement of the stem in the stuffing-box with this type of valve is sometimes an important consideration as in cases where there is a possibility of contamination of the fluid from the atmosphere.

A variation of the first type which is used in larger valves, known as the outside stem and yoke type (O.S.Y.) is shown in Fig. 2. In this type the stem slides but does not turn in the stuffing-box. Threads outside the stuffing-box engage a hand-wheel which is held in place by a yoke.

Many variations of the fundamental gate-valve design have been introduced with the object of making them more adaptable to certain specific purposes or facilitating their maintenance. The clip-type gate valve, in which the bonnet is fastened to the body by means of a large U-bolt, passing around the body, has important advantages for chemical industry use in that its parts are readily renewable and there is a minimum number of threaded joints in the valve.

Troubles With Gate Valves

Gate valves have certain disadvantages which sometimes make them unsuitable for chemical plant use. When the fluid contains suspended solids or crystals, gate valves will operate satisfactorily only with the stem in a horizontal position. With the stem down, the bonnet will fill with sediment and prevent operation while, with the stem vertical, the groove at the bottom tends to fill, preventing tight closure. Such troubles can sometimes be overcome by drilling the valve case and connecting a $\frac{1}{8}$ or $\frac{1}{4}$ in. water or air line so placed that the sediment can be flushed or blown out.

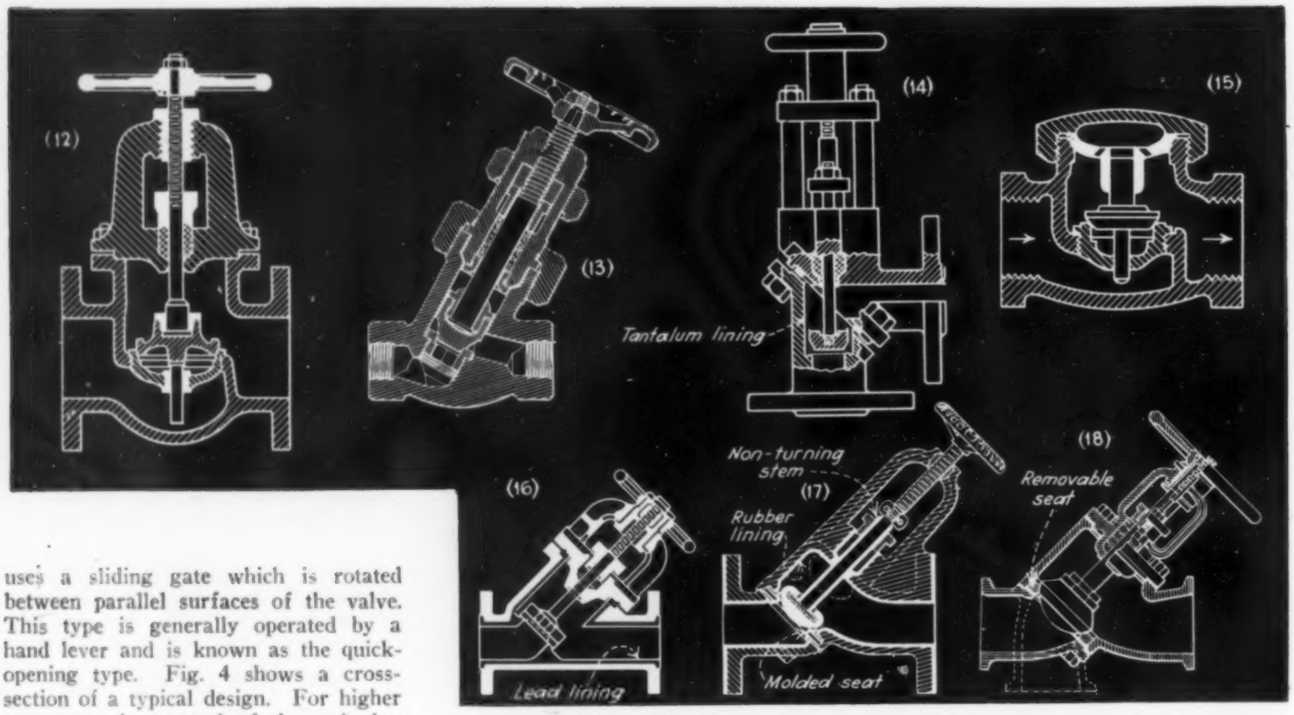
When used for high pressure or even moderate pressure in the smaller sizes, or vacuum in the larger sizes, the total force against the closed gate becomes troublesome, making a gate valve difficult to open or close. Also, heavy construction is required. The difficulty in operation may be partially overcome by use of a bypass line around the valve, equipped with a globe valve in the bypass which can be opened before operation of the gate valve to relieve the pressure. Many large gate valves are provided with outlets in the case for this purpose. Sometimes the bypass is a part of the case itself. The double-disk type of valve previously mentioned requires no bypass owing to the fact that there is no sliding engagement between the disk and the seat.

One gate valve is available in which the seat surfaces are lubricated by means of a screw-type grease gun. This type, shown in Fig. 3 is a Reading-Pratt & Cady design. Seat corrosion is lessened and the lubrication facilitates operation.

Another variation of the gate valve

uses a sliding gate which is rotated between parallel surfaces of the valve. This type is generally operated by a hand lever and is known as the quick-opening type. Fig. 4 shows a cross-section of a typical design. For higher pressures, the control of the swinging gate is generally through gearing.

Butterfly type valves are similar to gate valves in that they do not change the direction of flow to any great extent. In this type the gate, instead of moving in a vertical plane, turns on an axis. Butterfly valves give excellent control of gases and vapors but cannot be used where tight closure is required.



Figs. 12-18—Globe valves and modifications, including plug, angle, check and Y valves

Plug Cocks

Historically, cocks are probably the oldest type of valve. In their earlier forms, so many difficulties attended their use, chiefly because of leaking and sticking, that a natural prejudice developed against them. In modern cocks for chemical plant service, all these difficulties have been overcome to such a marked degree, chiefly through the use of pressure lubrication of the plug, that the newer designs find extremely wide application in most of the process industries. It was largely through the work of the Merco-Nordstrom Valve Co. that the way toward the design of suitable cocks for severe service was pioneered.

A cock resists corrosion because the machined surfaces in contact with the liquid are not those used for shut-off. In some of the earlier cocks, and, in fact, in some that are still made, the opening through the plug was circular. It is evident from Fig. 5 that such a design does not give good regulation since at positions near opened and closed a large movement of the actuating lever is necessary to effect a small change of flow. Furthermore, this type of opening gives rise to eddy currents and flow disturbances. More recently, cocks have been made with the plug openings roughly rectangular in shape. With this type of opening the flow characteristics are much improved and movement of the operating lever provides for more nearly uniform variation in flow.

In the older non-lubricated cocks, the machined surfaces could be kept from leaking only by keeping the plug so tightly in place that it soon froze and could not be moved. Any attempt to overcome this trouble by increasing the taper resulted in the lifting of the plug by liquid pressure and consequent leakage and ultimate corrosion. With the development of the lubricated type now available, the barrel can be held tightly in place and still is movable without difficulty. Should the valve stick through long disuse, the lubricant can be forced through the grease passages under high pressure, loosening the plug.

Owing to the smooth passages possible in modern cocks, the resistance to fluid flow is usually lower than in other valves. Furthermore, solid particles cannot deposit within the valve. It has been the writer's experience in design and operation of equipment where control of flow is important, that a lubricated plug cock provided with a suitable lever on a quadrant furnishes a better degree of regulation than is obtainable either with gate or globe valves. By increasing the length of the lever, very close adjustment can be attained and by placing a stop clamp on the quadrant, the lever can always be brought to the same known position. Should solids deposit on the plug when it is in a partially opened position, the lever can be moved occasionally to dislodge the particles and then brought back to the same position. For very fine and accurate throttling of flow, a gear or worm and gear reduction can be used in controlling the position of the plug.

In Fig. 6 is one of the simpler Merco-Nordstrom plug valves, often used in chemical plants. The function of the gland and gasket rings is to hold the plug on its seat. A metal diaphragm beneath the rings of packing serves to confine the fluid by means of a metal-to-metal seal on top of the plug. Fig. 7 shows the "Hyperseal," the latest type of plug valve made by this company. Here the shank is separate from the plug, which is full-floating. It is completely thread-lubricated and all forces are balanced except on the projected area of one port when closed, and two ports, when open. The cover itself is used as a spring with a calculated degree of flexure to furnish the yielding means. Thus gasket rings which tend to change in resilience under the action of heat and chemicals are eliminated. In this valve, leakage around the holding screw is prevented by a flexible metal diaphragm.

In the stem of this valve is an equalizer with circular stuffing-box. The packing for this stuffing-box consists of a "packing stick" forced into the

chamber around the threaded stem. This permits the use of a plastic packing and makes it possible to pack the valve under pressure through the ball check. Softening of the valve lubricant under high temperatures is thereby overcome.

In addition to the two-port varieties, cocks are made in multi-port designs as in Fig. 8. At Fig. 8*a* is a three-way, two-port valve, while *b* and *c* show respectively a three-way, three port; and a four-way. Care must be taken in the installation of the type shown at *a* since it cannot be kept tight if installed in such a position that the line pressure tends to force the plug away from the closed port.

In the larger sizes, Merco-Nordstroms use a type of construction indicated in Fig. 9. The venturi-like passage is designed to give the lowest possible pressure drop through the valve.

In Fig. 10 is a design of non-lubricated plug cock recently developed by the Homestead Valve Co. In this cock, positive mechanical seating and unseating are provided by means of a lifting handle. Before the plug is changed to a new position, the lifting mechanism is operated. Then the plug is turned, after which it is reseated. Another design of non-lubricated cock made in chemical stoneware by the General Ceramics Co., employs a wedging action to release the plug. Inserted between the top of the plug and the body of the cock is a ring containing two depressions which register with projections on the plug top. Turning the handle first lifts the plug slightly, then turns the plug to its new position.

Globe Valves

The valves which have previously been described all use a sliding surface to obstruct the flow. Globe valves, however, and several others of somewhat similar construction operate by plugging a hole in the valve. Globe valves themselves vary considerably in construction details, but are all characterized by a shape of body in which a more or less abrupt change in flow direction must take place in passing through a seat disposed in a plane parallel to the flow. The most common variations in globe-valve design relate to the type of closure. In one form a cone-shaped portion is pushed into the seat whereas in another a disk of some resilient material, resistant to the fluid handled, is pushed down on the seat. Sometimes the disk is guided, and in smaller valves permitted to float quite freely. Fig. 12 shows a typical design.

Contrary to frequent practice, the common disk type of globe valve is not a satisfactory throttling valve. This is particularly true of liquids and especially so when the liquids contain solids in suspension. If a valve is to be wide open or closed in service, ordinarily a gate valve should be used. For throttling control, a cock, a ported balanced valve or one of the pinch valves later to be described is more satisfactory. In larger lines globe valves are not as satisfactory as gate valves because the heavy total pressure on the disk makes it difficult to keep tight.

When used in throttling service with steam, wire-drawing will often make the disk leak after a relatively short time. For such service, manufacturers have resorted to disks and seats made of extremely hard corrosion- and erosion-resisting alloys. Other expedients have also been used to improve throttling. One is to substitute for the disk nut a throttling nut containing ports which form orifices when the valve is opened. The disk is retained for shut-off but regulation is accomplished through the ports. Another means for improving the throttling characteristics is to use a plug or cone instead of the usual disk. Fig. 13 shows a Chapman forged steel plug valve which is of Y-design, giving less fluid resistance than the ordinary globe type. Valves of this type use specially hard alloys for the cone and seat.

Another modification of the globe type is the angle valve, one special form of which is shown in Fig. 14. This particular valve is tantalum-lined and employs a plug-shaped element instead of the disk usually associated with this type of valve.

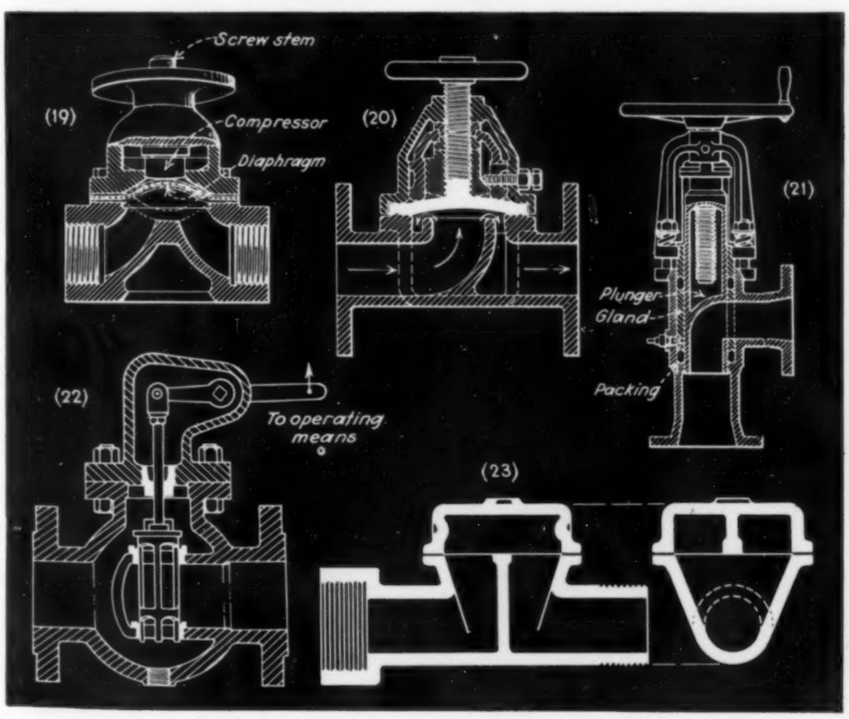
Still another modification of the globe type is the check valve shown in Fig. 15. Check valves are of many sorts, but in all of them an element such as a disk, a flap or a ball is forced into an orifice upon reversal of the flow.

Check valves cannot ordinarily be depended on to be absolutely tight, but will prevent the return of any large quantity of fluid. The type shown is generally made in the smaller sizes, while a type using a swinging flap gate, so set as to close by gravity, is used principally in the larger sizes. In certain types the disk is held closed by a spring. Very small check valves make use of balls instead of disks, a type of construction which has also been found satisfactory for larger sizes made of hard rubber. A modified form used in boiler work is known as a combined stop and non-return valve. This prevents the return of steam to a boiler when the pressure in the boiler drops below that in the header.

Another variation of the check valve is the back-pressure valve. When used for very low pressures, these may be counter-weighted and fitted with dash pots to prevent chattering.

Valves of the Y-type are also modified globe valves. Several special designs are shown in Figs. 16, 17 and 18. Aside from the fact that the Y-valve gives a more nearly straight flow-line than the globe valve, it also possesses other advantages such as the possibility of having the seat readily accessible for replacement. This type, consequently, is often used for chemical

Figs. 19–23—Miscellaneous valves including pinch, seatless and balanced valves and a special stoneware type



valves made from some of the special materials of construction. In Fig. 16 is a Resisto lead-lined valve. A Vulcalock rubber-lined valve appears in Fig. 17, while Fig. 18 shows a Y-valve of alloy steel made by the Duriron Co. It is clear that by rotating the lower part of the body 180 deg. this can be made into an angle valve. A similar design is used for Duriron and Corrosiron high-silicon iron valves.

Needle Valves

Where the fluid is clean and a high degree of regulation is necessary, a modification of the plug type of valve is often used. This is the so-called "needle valve" in which the end of the stem is shaped into a cone point or needle. Ordinarily the seat in this type of valve is not removable. It is made both in globe and Y designs. Its fluid resistance is high, but its regulation extremely accurate. In comparison with other valves, its size is necessarily large for a given quantity of fluid handled. However, the same basic principle has been applied to the very large valves used in controlling the flow of water at Boulder Dam.

For chemical plant service, an important consideration in the design of valves is the possibility of repacking the stuffing-box under pressure. Many valves are so designed, having a shoulder on the stem which in the full open position makes contact with a ground surface in the top of the bonnet. Another consideration, particularly with globe valves, is that the disk be of a type capable of ready replacement or that both disk and seat be capable of regrinding.

Pinch Valves

An extremely simple and effective method of regulating flow through acid hose is to employ an ordinary pinch clamp similar in principle to the laboratory pinch clamp. A refinement of this idea has been used in rubber-lined valves having a removable and replaceable rubber sleeve lining. Here a compressor which is part of the valve body can be screwed down to close the sleeve section by pinching. A still more recent modification of this principle is found in valves using a flexible diaphragm, usually of fabric-reinforced rubber, which can be pushed down so as to close off the flow passage.

Particularly in the handling of corrosive liquids and those containing suspended solids, it has long been the aim of valve designers to remove as much as possible of the valve mechanism from contact with the liquid. Except for small radiator valves in which a flexible metal diaphragm has been employed to eliminate packing, this aim does not appear to have been achieved fully except in the case of the pinch valves. The simplest type mentioned above, that is, the clamp applied to a rubber tube, is remarkably effective in many cases. Surprisingly enough, it lends itself well to automatic control of liquids containing large quantities of suspended solids which might easily clog other types of valves. A diaphragm motor operating a compressor on a section of rubber tube operates very successfully in this application.

Two recent applications of this idea appear in the diaphragm pinch-type valves shown in Figs. 19 and 20. The Saunders valve made by Hills-McCanna Co. appears in Fig. 19. The screw mechanism is completely separated from the liquid chamber by the flexible rubber diaphragm. The body of the valve resembles two elbows placed back to back with a chamber at the top. Liquid entering the first elbow is directed upward against the diaphragm and down in the second elbow. When the diaphragm is depressed, the diaphragm is forced against the wall between the two elbows, making a tight closure. In the open position, the passage area is over 100 per cent of the pipe size.

It is obvious from the illustration that perfect machining is not required and that the valve functions without lubrication and with low fluid resistance. There is no packing and the only maintenance is occasional replacement of the diaphragm. Numerous body materials such as chemical stone-ware, glass-enameled steel and plastics can be used. Hence, the only limitation on the use of the valve is the resistance of the diaphragm. Rubber compositions are in use at present but with the development of fiber-glass fabrics, with or without impregnation, there seems the possibility of using such materials for difficult applications. Such valves are made at present in sizes up to 12 in., for working pressures up to 150 lb. per sq.in. and temperatures to 180 deg. F.

Another valve operating on a similar principle is the Shriver diaphragm valve shown in Fig. 20. In this valve also, moving parts are completely separated from the liquid and no packing is required. A valve similar to this type is made for automatic pressure release in lines between pumps and filter presses.

Seatless Valves

Since it is with the mating surfaces in valves of the usual type that most difficulties are encountered in chemical industries, many attempts have been made to eliminate disks and valve seats. An outstanding example of success in this direction has been achieved in the Yarnall-Waring seatless valve which has found application in the handling of slurries, viscous products and pulp digester blowdown. This valve, shown in Fig. 21, makes use of a sliding sleeve portion containing the flow passage. When the valve is closed a follower gland is forced down by the stem, thereby expanding the packing at two points to insure tightness. Proper functioning depends on the use of suitable packing and lubricating material.

Regulating and Other Valves

Generally, automatic regulation depends on the use of especially designed valves, some of which will be touched on in other articles of this section. Fig. 22 shows a Copes balanced valve, illustrative of a method which, in numerous variations, is generally relied on for automatic control purposes. Owing to the balanced design, the requirements of sensitivity, under the small operating force generally available, are met by this type. Modifications of the porting arrangements are introduced to give various sorts of flow characteristic to the valve.

Throttling valves, such as have already been described, lend themselves to this type of work. Furthermore, with recent refinements in the lubricated plug cock, new possibilities for its use in control have become apparent.

In Fig. 23 is a special type of valve which is one of many designs developed for special purposes. This is a chemical stoneware valve made by the General Ceramics Co. and as will be evident from the two views, consists of a body containing a barrier surmounted by a top portion containing a mating barrier. Ground surfaces in the joint keep the valve tight for low pressures. It is operated by turning the top so as to rotate the partition, either to mate with or cross the barrier which is in the body portion.

Another class of special valve which should be mentioned generally results from the ingenuity of the plant designer or operating man on the job. This is the liquid seal which is found frequently in lines handling gases at pressures near atmospheric. A recent commercial application of this idea has been developed for sealing individual ovens in a coke-oven battery and so shutting them off from the collecting main.

In conclusion, the writer must disclaim any attempt at complete coverage of the valve picture. If what he has written will clear away a part of the mist surrounding a subject with so many modifications, "ifs and buts," he will have accomplished his purpose. Just one more suggestion: identification of valves in the piping layout is a most useful expedient. Valve wheel covers of different colors, marked for fluid service and thus capable of ready identification have prevented many a bad error in emergency operation. Valve position indicators are another accessory often essential in guaranteeing good plant operation.

Remote Valve Operation

EDITORIAL STAFF

CONTROL of fluid flow often requires closing and opening of valves that have to be placed some distance from the operator and hence are inconvenient for him to reach. There is a tendency to provide such valves with mechanisms that permit their manual operation from remote stations.

Remote valves may be manually controlled electrically with motor, solenoid, Thrustor or synchro-tie motor, or by fluids such as compressed air and water. When the valve is not too distant, manual operation through rods, gears or cable is possible.

Large globe and gate valves are usually operated by a motor or hydraulic cylinder. Figs. 1 and 2 show valves equipped with motor operators. In Fig. 1 the operator is applied to a gate valve, the motor driving through a combination helical and worm gear reducer. Opening or closing the valve is started by hammer blows imparted by lugs in a lost-motion arrangement which gives the motor opportunity to come up to speed. Thrust created against the worm is resisted by a preloaded spring which controls the seating force. When this force produces a thrust against the worm that exceeds the initial spring setting, it causes the worm to move on a splined shaft, further compressing the spring. This trips a limit switch and shuts down the driving motor. A clutch is provided in most cases to permit hand operation. Of course the push buttons controlling the motor may be placed at any convenient location and signal lights may be arranged to indicate whether the valve is wide open or closed. When operation requires the valve to be partly opened or closed, some kind of position indicator should be installed. This can be done by gearing a Selsyn motor to the valve stem and gearing the receiving Selsyn to a dummy valve stem or indicator.

Synchro-tie motors offer a means of remote manual valve operation whereby the valve setting may be changed any desired amount with a direct indication of valve position. The system consists of duplicate motors, one a transmitter manually operated in the same manner as a valve hand wheel. The other is a receiver coupled to the valve stem and electrically connected with the transmitter so both will remain in phase. Any movement of the transmitter causes a like movement of the receiver.

A balanced valve with motor operator is shown in Fig. 2. The motor operates through gears to turn plate *A* which makes a half revolution and then stops, thus operating the valve from closed to full open. Springs in the linkage provide for proper seating force.

Small valves—up to about 2½ in.—(Fig. 3) may be operated directly by a solenoid. With a solenoid, the valve can be either open or closed; intermediate positions are not possible. Larger valves, when it is necessary to open them many times a day for relatively short intervals, may be operated by a G. E. Thrustor, Fig. 7. This consists of a motor-driven centrifugal pump inclosed in a cylinder containing oil. When the pump operates it supplies fluid pressure under a piston which moves to open the valve. Spring action closes the valve when the motor-driven pump stops.

Fig. 4 shows a valve provided with a cylinder for hydraulic operation. To open the valve, liquid under pressure is supplied to the under side of the operating piston and exhausted from the top side. Control of operating fluid is by a four-way pilot valve such as that shown in Fig. 5. With this type of valve, operating fluid must be piped from pilot to valve, and if the distance between them is large, valve operation may be sluggish. To overcome this the pilot may be solenoid operated as in Fig. 6 and placed close to the hydraulic cylinder.

Ordinary diaphragm-top control valves can be used for remote manual control. Compressed air is supplied to a manually operated leak valve with which the pressure on the diaphragm, and hence the opening of the main valve, is regulated. The degree of opening is shown by a pressure gage at the leak valve.

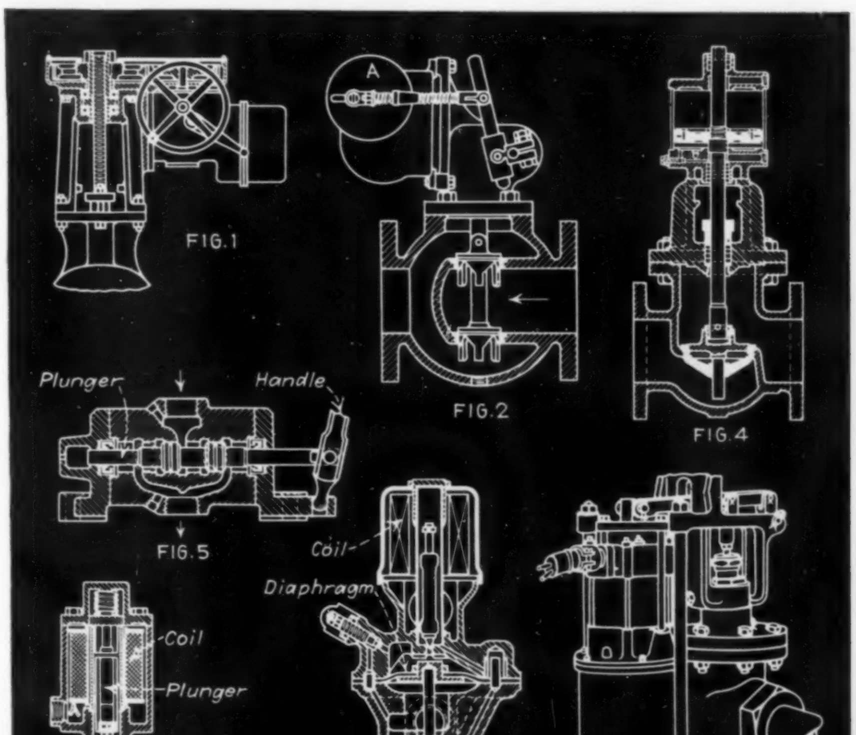


Fig. 1—Motor operator applied to gate valve; (2) motor-operated balanced valve; (3) solenoid operated valve; (4) valve operated by hydraulic cylinder; (5) control for hydraulically operated valve; (6) pilot operated solenoid valve; (7) Thrustor operated valve

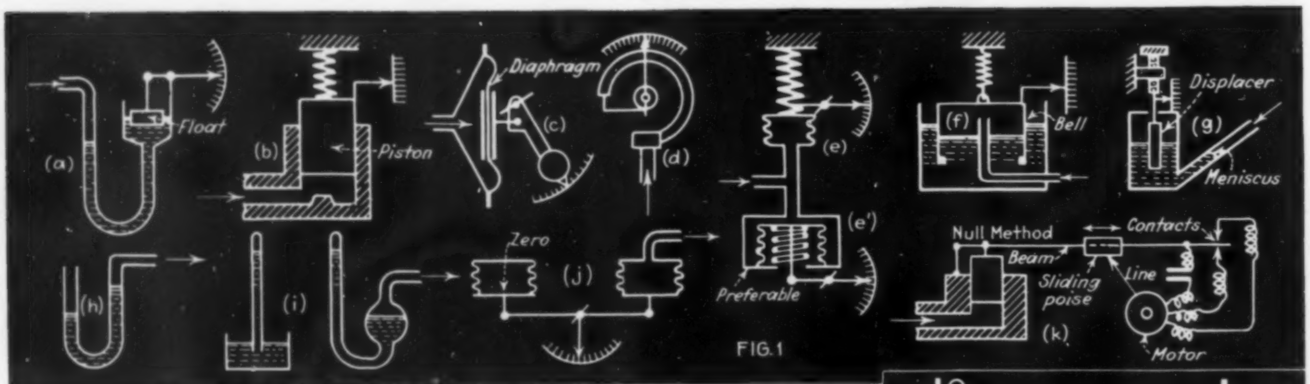


Fig. 1—Devices for hydrostatic pressure measurement

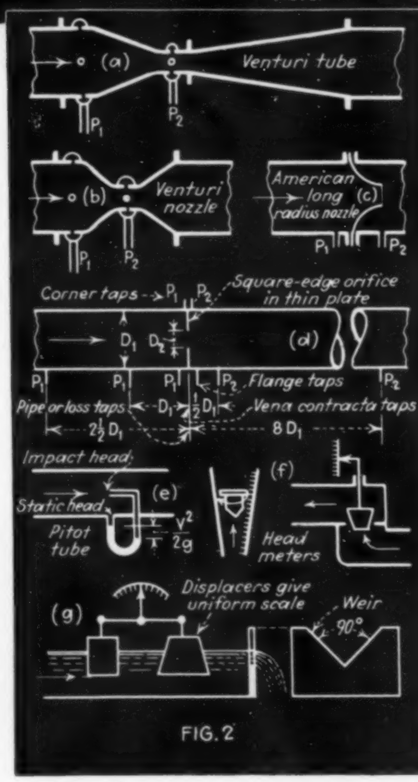


Fig. 2—Typical head meters

Fluid Measurement and Control

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In preparing the accompanying notes, Mr. Smith, who is chairman of the A.S.M.E. Process Industries Division's Committee on Industrial Instruments and Regulators, wishes to invite correspondence of chemical engineers with this committee. Comment on such topics as terminology, applications, installation and selection of regulators is desired, with the particular object of furthering the committee's discussions at the society's annual meeting next December.—Editor.

FLUID MEASUREMENT and control deal both with static and with flowing fluids, the former being much the simpler of the two, but no less important in that the principles used in the measurement of "hydrostatic pressure" are also those met in flowing fluid measurement and control. Commercial measurement of hydrostatic pressure consists merely in recording a level, either of the fluid under consideration, or of another liquid in a U-tube (Fig. 1*a*). Sometimes a differential piston is used (Fig. 1*b*) or a diaphragm (Fig. 1*c*), opposed by a weight, a spring or its own elasticity. The bourdon tube and the Sylphon bellows (Figs. 1*d* and *e*) are important static pressure measuring means and for pressures or suctions near atmospheric, the liquid-sealed bell (Fig. 1*f*) is useful. Many ingenious novelties have been applied to the extremely accurate measurements required in laboratory work. Among these is the Hodgson micromanometer (Fig. 1*g*) in which a relatively small displacer is moved by a micrometer in the large leg of an unsymmetrical U-tube until the magnified edge of the meniscus in the other leg reaches a definite point.

For the measurement of moderate vacua, the depression relative to atmospheric pressure is generally measured in a simple U-tube (Fig. 1*h*) with a single liquid or two of slightly different densities. Very low absolute pressures are commonly measured either with a barometer (Fig. 1*i*) or by comparing an evacuated diaphragm with another diaphragm subject to the low pressure being measured, both immersed in the atmosphere (Fig. 1*j*).

Where bourdon gages are measuring fluctuating pressures, as from high speed reciprocating pumps, pulsation deadeners are necessary. A better and more accurate method, which averages the fluctuations and is also being used increasingly where high accuracy is required in other cases, is to use a piston exposed to the pressure, counterbalanced by a beam carrying a sliding weight electrically driven to maintain balance at all times (Fig 1*k*). This so-called null method, used also with diaphragms and bellows, has various modifications whereby the pressure can be opposed and balanced as by electromagnetic means in which case the pressure is indicated by the corresponding balancing current.

Flowing Fluids

A flowing fluid possesses certain mechanical properties which can be measured and from which the rate of flow can be determined. A gas or liquid flowing in a pipe possesses at a particular section a certain "potential head" owing to the elevation of that point above an arbitrarily chosen point; a "velocity head," by reason of its velocity; and a pressure or static head, by reason of the pressure in the fluid at that point.

In addition, the fluid possesses a definite volume under the particular conditions of pressure and temperature maintaining. Two sorts of meters making use of these properties are available: head meters which give as an indication the instantaneous flow rate; and velocity and displacement meters which directly determine the total flow over a period of time. Among the first sort are the following:

(1) Neglecting friction, the sum of the several heads remains constant from point to point in an isolated system, according to Bernoulli's theorem. Hence, changing one head will produce a corresponding and measurable change in another. Using an orifice, nozzle or venturi tube (Fig. 2 *a*, *b*, *c* and *d*) to increase the velocity for a short distance, it is easy to measure the resultant change in static head between points above and at the constriction, or below it. This change can then be used as a measure of the flow rate.

(2) The impact pitot tube (Fig. 2*e*) measures the velocity head ($V^2/2g$) directly and permits ready calculation of the velocity at the point where the impact opening is inserted.

(3) Various "area" meters (Fig. 2*f*) have been devised which make use of a variable orifice area, proportional to the flow rate, and maintain a constant static pressure differential regardless of the rate. These meters operate on the same principle as the orifice and venturi types except that the differential rather than the orifice size is held constant.

(4) In the case of an open channel, a weir or obstruction (Fig. 2*g*) placed across the path of flow will back up the liquid and the height of the crest above the weir vertex will be proportional to the volume of flow.

Among the second groups of meters, those directly totalizing flow volume over a period of time are: (5) The velocity type, which is somewhat similar in principle to the head meters, employing a light propeller, helix or member carrying cup-shaped elements, placed in the line of flow, and rotating at a rate proportional to the velocity of flow. Anemometers, turbine and shunt meters (Fig. 3*a*) are of this type, sometimes employing a hydraulic drag on the rotating element to increase the accuracy of measurement.

(6) The displacement type of meter resembles the velocity type in totalizing flow. The volume flowing is measured directly by repeatedly filling a known volume of the meter and recording the number of fillings in a definite period of time. Piston and nutating disk meters (Fig. 3*b*) for liquids, dry-disk, wet (Fig. 3*c*) and cycloidal meters (Fig. 3*d*) for gases, are examples.

(7) Finally, there are several methods based on the addition of heat or certain materials to the flowing fluid. Among these is the Thomas meter, which adds just sufficient electrically produced heat to the fluid to raise its temperature a small but definite amount, measuring the quantity of electricity required and recording it in terms of the flow. Or, a chemical can be added at a constant rate and the dilution determined by analysis at a point downstream far enough for thorough mixing to occur. Similarly CO_2 is sometimes added to steam in metering the latter.

Most fluid metering in the process industries is accomplished with head meters and the types using a venturi tube, nozzle or orifice to produce a differential pressure are commercially the most important of these. In practice, the orifice is mostly used for gaseous fluids where deposits of dirt from the gas are less than for nozzles and venturis. The nozzle is useful where large flows are encountered while the venturi, with its efficient downstream recovery cone, is used mainly for large lines carrying liquids where the pressure loss must be kept to a minimum. So many data have been obtained with orifices for various connections, by organizations such as the A.G.A. and A.S.M.E., that this ideally simple device has recently gained favor over the nozzle and venturi. The latter are obviously more difficult and expensive to make properly. However, the A.S.M.E. is now obtaining data on these to show their true performance relative to orifices.

Less used, but still important particularly in the measurement of flow of gases and vapors in comparatively large ducts or at high velocities is the impact pitot tube. This device (Fig. 2*e*) consists of a small tube usually centrally located in the duct, pointing against the flow and connected to one leg of a U-tube manometer. A static pressure connection, often in the wall of the duct, is connected to the other leg of the U. Thus the U-tube measures the difference between the impact and static pressures, giving velocity-head directly. A proper pitot tube accurately follows the equation $V = \sqrt{2gH}$, where V is the velocity in feet per second, g is the acceleration of gravity and H is the velocity head in feet of the fluid flowing. Since the velocity distribution in the duct is not uniform, the average velocity in the pipe will vary between 0.5 and 0.83 per cent of the velocity indicated by a central impact tube with a static pressure tap at the pipe wall. Fig. 5*a* shows how it varies with the Reynolds number.

For flow in open channels, the use of a weir was mentioned. An open channel gets away from the pulsation effects which may cause head-type meters to read high. The 90-deg. V-notch weir (Fig. 2*g*) is the most accurate and popular of the open channel meters, being suitable for small to moderate flows. One formula is

$$Q = 0.3108h^{2.492}\nu_s^{0.012} \quad \text{........(1)}$$

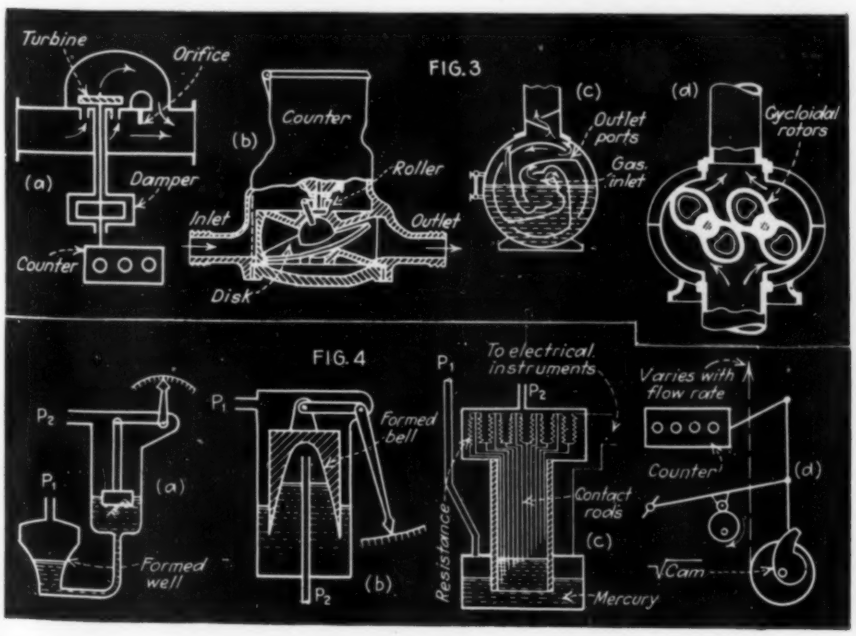
where Q is the flow in cubic feet per minute, h is the inches head above the vertex of the notch and ν_s is the specific kinematic viscosity relative to water at 68 deg. F.

Methods for determining the heads and hence the flow rates with the differential pressure meters are similar to those used for static fluids. Some form of U-tube manometer is almost universally used with venturis, nozzles, orifices and pitot tubes. Since the flow rate with each of these methods is proportional to the square root of the indicated differential head, recording meters either have unevenly spaced charts graduated in terms of flow units or an even head spacing which must be interpreted with a square root table of "extensions." However, several ingenious variations of the ordinary U-tube manometer have been developed to take care of the embarrassing square root relation.

One method is to give a special shape to one leg of the U-tube (Fig. 4*a*). Another is to use a special form of cylindrical bell (Fig. 4*b*) or, alternatively, to use a plain cylindrical bell with a formed displacer. Still a third is to place a specially filed cam between a U-tube float and its indicator. One method is to balance the U-tube itself on knife edges and oppose its tilting by a cam and weight. Among several electric flow meters is one (Fig. 4*c*) in which a clean mercury surface progressively touches a number of contacting points surrounded by clean oil, to connect through square root resistors with an ammeter which is read directly in flow rate units. Still other electric flow meters use a rotating cam in the manometric transmitter to create cyclic electric impulses varying in duration with the flow rate. In some of these the square root is taken by the shape of the rotating cam itself.

To record total flow, some form of integrator is required. Integrators may be either cyclical or continuous, mechanical or electrical. The continuous type generally uses a constant-speed friction disk on which a wheel driving a counter rolls at a radius proportional to the discharge rate. Common forms of cyclical integrator employ a square root cam, flat as in Fig. 4*d*, or cylindrical. A more recent type uses the variable-duration impulse method of telemetering to drive a counter through a self-starting synchronous or sub-synchronous motor. Standard electrical wattmeters and like devices are creeping into industrial flow metering because of their excellence and low cost, serving as integrators for various electric flow meters in which the indication is converted into a current

Fig. 2—Turbine and displacement meters
Fig. 3—Square root extractors



value. Modern integrators for the flow of compressible fluids are available to take account of their density variations.

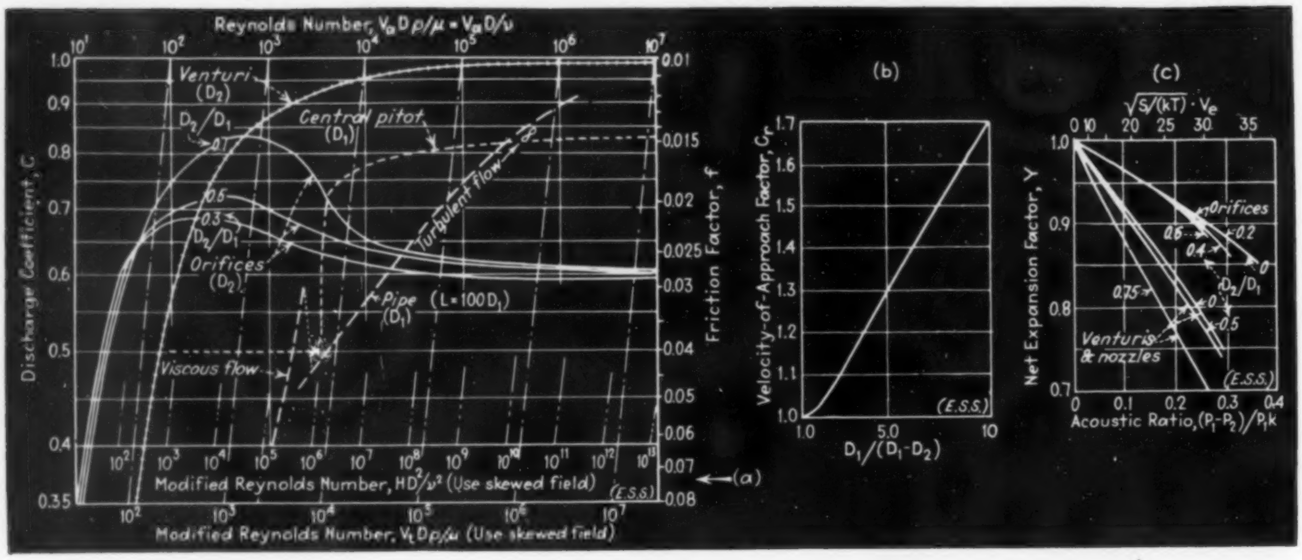


Fig. 5—Discharge coefficients, velocity-of-approach factors and net expansion factors for differential producers

Flow Meter Calculations

Naturally, differential pressure meters still follow the same physical laws they have always followed, but calculations pertaining to them have been streamlined and greatly speeded up. The simple hydraulic equation:

$$Q = CC_rA_2Y\sqrt{2gH} \ldots\ldots\ldots (2)$$

has replaced the thermodynamic equation, being used for both liquids and gaseous fluids. Here Q is flow rate in cubic feet per second; C is the "hydraulic coefficient," which depends on the Reynolds number; C_r is the velocity-of-approach factor, which takes care of the fluid velocity upstream from the orifice or other differential producer; A_2 is the throat area of the differential producer; Y is the "net" expansion factor (taken as 1.0 for non-compressible fluids), which for gases and vapors varies with the "acoustic ratio"; g is the acceleration of gravity, 32.16 ft. per sec.^{2}; and H is the differential pressure in feet of the fluid flowing.

Where a fluid flows through a constriction, the pressure drop indicated is due mainly to the change in velocity head, but partly to the fact that there is a small friction loss through the constriction. Furthermore, in some differential producers, such as the ordinary square-edged, thin-plate orifice, the jet contracts so that the actual area of the flow section is less than the area of the constriction, and the velocity head increase is considerably greater than would be accounted for by the ratio of pipe to orifice area. Hence the hydraulic coefficient C is introduced to correct the observed pressure drop for friction and contraction. As is evident from Fig. 5*a*, the coefficient C varies with the Reynolds number for each of the several differential producers charted. The conventional Reynolds number $V_aD\,\rho/\mu$ appears on the upper abscissa scale. Here V_a is the average flow velocity in feet per second, either through the pipe of which the diameter is D_1 ft., or through the differential producer, diameter, D_2 ft., as indicated on each of the several curves. D is the diameter in feet of the flow section considered, while ρ and μ are respectively the density in pounds per cubic foot and absolute viscosity in pounds per foot per second. Two alternative, and sometimes more convenient, forms of the Reynolds number are given on the bottom scales, using the dot-dash skewed field. Here V_t is the theoretical velocity indicated by the differential, $V_t = \sqrt{2gH}$. On the right-hand vertical scale is the friction factor f for 100 diameters length of straight smooth pipe, thus relating this factor and C for the three forms of Reynolds number. Hence one can find the flow from the head or vice versa, by considering a length of pipe as a differential producer.

Fig. 5*b* evaluates the velocity-of-approach factor C_r by plotting against a new abscissa $D_1/(D_1-D_2)$ which gives a nearly straightline graph, for easy interpolation. Fig. 5*c* presents values of the net expansion factor Y which takes up the rest of the empirical slack in substituting the simple Equation (2) for the thermodynamic equation. It has been noted that Y is not needed, and is hence taken as unity in the case of liquids. With all fluids the transmission of pressure effects is limited in speed by the velocity of sound in the fluid. In the case of gases and vapors the expansion factor becomes important and the characteristics of the fluid and the design of differential producer both affect the differential that will be produced for a given flow. The factor Y for each of several differential producers is plotted against the acoustic ratio $(P_1-P_2)/P_1k$ on the bottom scale and the sometimes more convenient expression $\sqrt{s/(kT)} \cdot V_e$ on the top scale. Here P_1 and P_2 are respectively the upstream and throat pressures in pounds per square foot, k is the specific heat ratio C_p/C_v for the gas in question (1.3 for steam, 1.4 for air, 1.67 for helium), s is the specific gravity of the gas relative to air, T is the absolute temperature in degrees F. and V_e is the "actual" velocity at the effective area ($A_e = CC_rA_2$) feet per second. Knowing the actual flow, one can find Y and compute the differential; or knowing the differential, one can compute the actual flow. (Note: Graphs bearing the initials E.S.S. were developed by the author. The A.G.A.-A.S.M.E. committee on orifice coefficients has just reprinted its conclusions based on the Reynolds number and the author's acoustic ratio, a timely and extremely useful example of modern methods in metering calculations.—Editor.)

Installation of flow meters is an art in itself and only a few special points can be mentioned here. Care must be taken to prevent or compensate for flow disturbances upstream of the meter. Particularly, hazards must be avoided in using meters for chemicals. For instance, light hydrocarbons used as manometric liquids in a U-tube for measuring chlorine gas or liquid are likely to initiate explosions. Unless a stable sealing liquid, such as carbon tetrachloride, is used together with thin silver isolating diaphragms, mercury should not be used with chlorine. The use of mercury in flow meters for moist ammonia gas is to be avoided, owing to the explosion hazard, although dry mercury, with a dry sealing oil in non-trapping seals, is safe for liquid anhydrous ammonia, provided the U-tube has check valves that positively prevent "blowing" the mercury. However, seals are at best a nuisance and should be used only when absolutely necessary.

Automatic Control

Automatic controlling is of the utmost importance in chemical process industries since only through this means has it been possible commercially to advance from batch to continuous processes. Modern mass production rests on automatic control, which is not to be considered as a mere substitute for man-power, but rather as an improvement, making possible new products and new industries. Metering is generally of consequence in these industries principally in so far as it is used in controlling.

Control of fluids always involves the control of flow, and on this account always requires the use of some sort of valve, either regulated manually, or through automatic means. It is not always the flow rate *per se*, however, that is the factor which it is desired to control. Just as both static and flowing fluids may be measured, both may be controlled. Generally the control of static fluids is much simpler, involving either the control of the pressure within a system (gases or vapors) or the control of level within a system (liquids).

For pressure control numerous sensitive devices are available, generally employing a diaphragm, bellows, or bell as the pressure measuring means. Movement of the pressure sensitive device may be tied to the valve directly, or through some mechanism which uses the primary impulse to control a supply of energy sufficient to operate the valve. This energy may be either that of the fluid itself or of air, water or oil under pressure, or of electricity.

The first type, the self-operating, self-contained regulator, has many modifications including the simplest governors used in the gas industry (Fig. 6*a*), and the smaller pressure reducing valves for steam. Such a regulator is satisfactory where a fair operating range, more than about 4 per cent of the full range, is permissible and when there is not much process lag. For closer control, within 3 per cent of the full range or even closer in some regulators, where there is no process lag, a small leak of the fluid being controlled can be bled from the high to the low pressure side through a pilot valve and used to position the control valve (Fig. 6*b*). This type of regulator is usually faster than the self-operating type, and more powerful. Still closer control, within about 2 per cent of the full range, can be obtained without hunting (when the process lag is small) through the use of a pressure-sensitive bellows operating a pilot valve to control the pressure of an auxiliary air supply applied to a diaphragm control valve (Fig. 8*c*). This last type can be provided with refinements such as will be discussed in connection with flow control, to take care of serious process lags. It is also built with an integral pressure indicator or record pen and chart. Extremely close control of low pressure or vacua is often accomplished with a spring-suspended bell (Fig. 6*d*).

In general, where the pressure of a gas or vapor is to be reduced to less than 57 per cent of the upstream pressure, it is necessary to use two regulators in series. At this critical pressure drop the flow through a given size of valve opening depends only on the upstream pressure, jumping sharply with fluctuations in the supply. Lowering the pressure in two stages, e.g., from 100 to 25 lb. in the first stage and 25 to 18 lb. in the second, permits smooth operation if sufficient capacity is present between the two valves.

Control of liquid level is in most cases very similar to pressure control. A float on the liquid surface can operate the supply or discharge valve directly. For closer control, the float can position a pilot air valve which in turn controls the pressure on a diaphragm valve in the supply or discharge line.

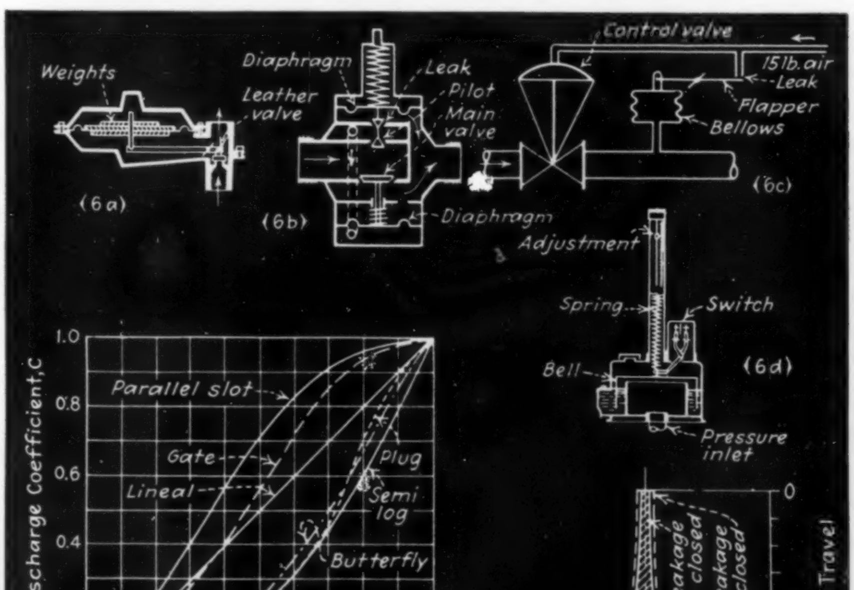


Fig. 6—Typical pressure controllers in diagrammatic form
Fig. 7—Valve characteristics and a good control valve slot

Flow Control

Flow control is somewhat less simple, but at the same time, much more interesting than the foregoing. A flow controller consists in brief of a meter controlling some actuating device which, in turn, controls a valve. But it is obvious that simply hooking together a meter, a motor and a valve does not necessarily make a satisfactory regulating instrument. Complications arise from the fact that the process ordinarily encounters various sorts of lag between the primary response of the meter and the completion of the correction by the valve. That is, because of a lag in the response of the meter, a lag in the controller or valve, a storage lag in the process (is generally the most important in chemical processes), there exists a period when the meter cannot "know" what the effect of a correction has been. This produces hunting in the simpler sorts of controller, a condition which, however, is not necessarily harmful.

In developing a satisfactory controller, an important element is a suitable valve. When it is the only resistance in a pipe, a control valve follows the equation $V = C\sqrt{2gH}$ so that its metering characteristics can be expressed by a discharge coefficient C. In Fig. 7*a* this coefficient is plotted against the degree of opening for three conventional valves, a gate, a plug and a butterfly valve, in comparison with three control valves. When a control valve is part of a hydraulic system containing other resistances, the value of C is reduced.

Other than open-and-shut valves, which are used for the simplest control, a control valve must be of a type capable of operating satisfactorily in a variety of positions between open and closed. Such valves have a port of suitable shape which is progressively uncovered as the valve opens. The shape of this port obviously determines the relation between the discharge rate and the degree of opening and also determines the amount by which the discharge will change for a given lineal change in opening. Referring again to Fig. 7*a* it will be evident that the parallel slot valve is almost useless as a controller when nearly opened. The lineal discharge valve gives a good characteristic in its middle-to-open range, but causes too large a percentage change of flow in relation to travel at low discharge

rates. The so-called semi-log valve, the discharge of which plots as a straight line on a semi-log grid, gives equal percentage changes in discharge for equal intervals of travel. This last type will take care of most installations met in actual practice, although the lineal valve is ordinarily satisfactory with air-operated diaphragm valves where storage lag is not serious. When storage or other lag does exist the semi-log valve is easier to stabilize. Probably a valve with a characteristic between the lineal and the semi-log is most satisfactory for all-around purposes, although it is interesting to note how good are the characteristics of the butterfly and even the plug valve. Fig. 7b shows a good shape of slot for a control valve. (Some recent notes by the author on valve selection appeared in *Instruments*, Mar., 1937, pp. 75–82).

For gases and viscous or gassy liquids, a control valve should be larger than for the same flow of a water-like liquid of the same density. Cocks with grease-packed stuffing boxes, butterfly valves and valves with flexible diaphragms to eliminate stuffing boxes are particularly applicable to chemical processes. In choosing the size of valve, the tendency is to use one that is too large. As rough rules: a valve more than half the diameter of the line is too large; furthermore, the loss in the wide open valve should be as great as that of the rest of the system to insure control under all conditions.

Controlling the position of the valve in response to the indications of the meter is the next problem. The seriousness of the lags in the system determines the complexity of control mechanism required. In the simplest control, on-and-off, the valve has only two positions, namely open or closed (or nearly closed), moving to the open position when the meter calls for "more" and to the closed position when it calls for "less." Where it is necessary for the control valve to "throttle," various modes of control are possible, as illustrated in Fig. 8*a*. The extreme condition of a system which is steadily hunting is supplied by the on-and-off control. Many throttling type regulators, however, will produce this sort of control when the valve and meter are out of step owing to lag. Various improvements in this condition can be effected by changes in the controller, for instance, the addition of a damping factor which will rapidly decrease the hunting swings of the valve, bringing the flow rate back to the demand while at the same time compensating for the deficiency at the start of the correction by one or a few overswings. Then, under some conditions, particularly when the installation is especially engineered to make this possible, it is feasible to employ fully stable control in which there is no hunting whatsoever.

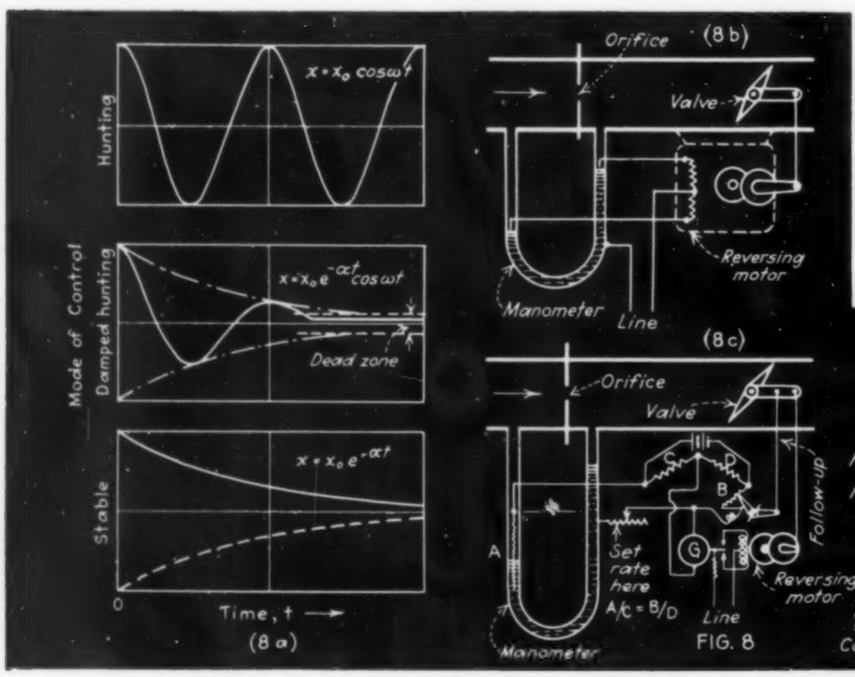
It is generally possible to obtain satisfactory control by treating the system as steadily oscillating, as portrayed by the hunting curve. Then all that remains is to improve the controller slightly and the hunting will stop. For example, the simplest thing to do when valve stability is required is to slow down its speed of operation. However, where sluggish action would permit the process to get out of control, it is vital to have a high speed of valve operation and to prevent it from over-traveling by means of some sort of followup. Such control is known as proportional control, the position of the valve being made accurately to *correspond* with that of the meter. Without a followup the control becomes *non-corresponding* or floating, and the valve, unless it is slow, may reach a position which has no relation to the requirements. Figs. 8*b* and 8*c* show simplified examples of non-corresponding and corresponding controllers.

The corresponding controller, with a change in demand, will not return the flow rate exactly to the control point. Should it be desired to do so, it is necessary gradually to break up the correspondence, which is essentially what is done in the numerous modern controllers having "automatic reset." Most of the air-operated controllers return the control point substantially to that set, but not strictly to a fixed point. This is sometimes and properly known as "pseudo-reset." Fig. 8*d* schematically diagrams a typical pseudo-reset controller. This refinement is amazingly inexpensive considering the results that are obtained on processes where storage lags and the necessity for a stable valve, operating at reasonable speed, exist together.

In an air-operated controller, using a spring-opposed diaphragm top for the control valve, the valve is essentially a corresponding device, provided that the control valve does not stick. Recently, a number of devices which serve as valve positioners have been introduced. In these the air pressure moves a small bellows connected by a followup to the main valve stem and to a small pilot air valve, so that the main valve is forced to go to precisely the right position, regardless of friction.

Some word is desirable in regard to valve actuating motors. A pilot-governed hydraulic cylinder has advantages in a non-corresponding controller owing to the throttling action of the pilot as it approaches its neutral position which makes it possible to speed up the cylinder considerably faster than usual electric motors for the same service. With a corresponding controller, either an electric motor or a hydraulic cylinder can be speeded up without hunting, since the valve is always constrained precisely to follow the meter. With a motor-operated valve, an interruptor-type device can be used to break up the correspondence by causing the valve to take extra short steps at regular intervals in the proper direction to correct for the meter's current direction of unbalance.

In conclusion, a warning, and an acknowledgment. The first: in this active art differences of opinion regarding a number of these notes are inevitable; the second, grateful acknowledgment to P. F. K. Erbguth, associated with the writer in the engineering department of Tagliabue, to whom he is indebted for the checking of this article.



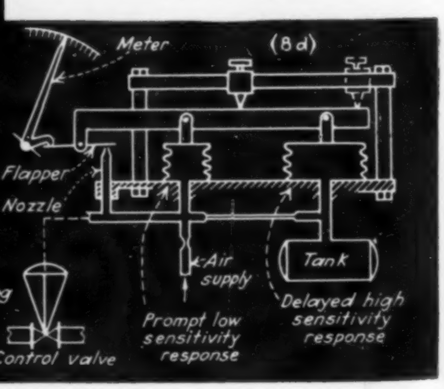
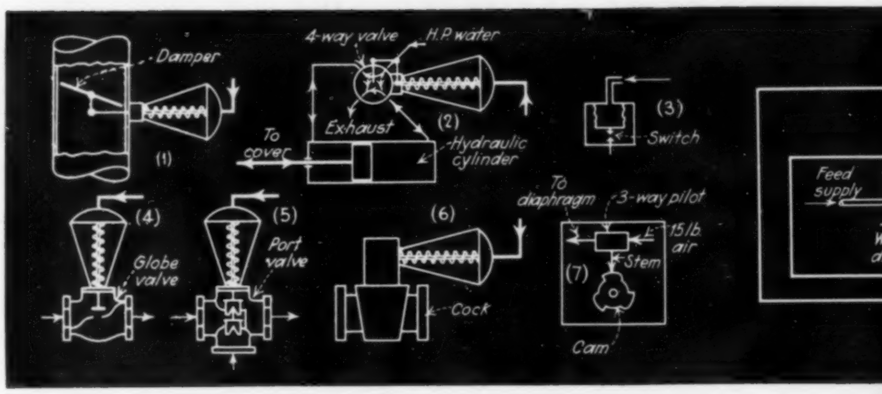
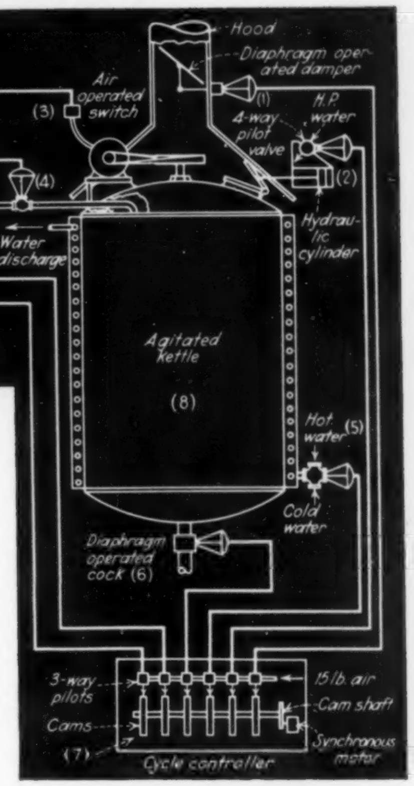


Fig. 8—Modes of control portrayed, with diagrams of three fundamental controller types





Elements of a simple coordinated valve-operating system

Coordinated Valve Operation

By L. B. LUMPKIN

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AUTOMATIC CONTROL of valve operation according to a time schedule has attracted a great deal of interest within the past few years. A remarkable degree of success has been achieved in developing this new technique in plant operation. When it is combined with control of process variables such as temperature, pressure or flow, completely automatic control of entire processes is possible.

The basis of automatic sequence operation of valves is the cycle controller which, in its simplest form, consists essentially of a battery of small three-way pilot valves, mounted on a common air manifold and operated by cams, so cut as to give the proper time sequence in the operation of diaphragm-operated valves, diaphragm motors, starters for electrical equipment and in setting control points for control equipment. With the cams mounted on a common shaft, turned by a synchronous motor, the whole is coordinated to a predetermined time schedule.

As an example of efficient and rapid operation of valves, in a recent installation in a tobacco processing plant, one of these systems operates 40 valves ranging from 24 to 2 in. in size, at least once every 2 minutes and some of them as many as six times. These valves are scattered over several floors of a large building and the saving in time, labor and power is apparent. Incidently, this installation cuts the required time for this particular process from several hundred hours to 30 minutes.

An interesting variation of this type of valve operation has been developed in connection with a recent solvent recovery installation where it was found that the schedule of operation of the recovery system had to be varied with respect to the number of units running in the factory. This was accomplished by having a telemetering system dictate to the control room from a distant point, driving the cam shaft at a speed proportional to the number of units running and their speed. Of course the control of temperature and other functions dictated by instruments must be interlocked with the cycle controller so that the required control functions can be completed in the allotted time.

For purposes of illustration let us assume a simple, hypothetical process and show how each function is handled. An agitated kettle is provided with an automatically opened manhole and hood for the venting of poisonous fumes while a batch is being processed. It is desired to start the agitator, run in a new batch and cool, then heat the batch according to a time-temperature cycle. When this is completed the manhole is to be closed and the batch dropped, all without attention from the operator except to push a start button.

Sketches (1) to (6) show the several parts of the coordinated system and sketch (8) the assembly. First the hood damper is opened, using a diaphragm operator (1). Then a pilot-operated four-way hydraulic valve, connected to a hydraulic cylinder to control the admission of water to the cylinder, opens the manhole cover (2). Then the agitator is started by the air-operated switch (3) and the batch run in by the feed line valve (4). The mixing valve (5), which is interlocked with a time-temperature controller (not shown) then admits cooling water for a definite time, then hot water for another definite cycle. As the heating cycle starts, the manhole cover is closed, and when it is completed, the cover is opened, the agitator shut down and the batch dropped by the diaphragm-operated cock (6). The cock and damper are then closed and the entire process shut down, ready for another batch.

All these operations are carried out by a six-cam cycle controller with six three-way pilot air valves, supplied with 15-lb. air and connected each to the proper diaphragm. One of the pilot valves is shown diagrammatically in sketch (7) while sketch (8) shows how each of the elements is tied in to the coordinated system.

Of course any of the above functions can be controlled electrically as well as by air. However, inasmuch as this is a discussion of valve operation, the fact is merely mentioned here.

The elimination of the human element in the operation of valves has several obvious advantages. Automatic control is more exact than manual, it is untiring and unforgetting and not subject to fatigue. The savings in labor and material which it makes possible are secondary to the improvement of quality and quantity of production which result.

In addition to the solvent recovery and the tobacco processes already mentioned, control systems of the type discussed have been applied successfully in plants manufacturing leather goods, textiles, plastics, woolens, rubber products of various descriptions, food products, safety glass, special color printing, solid carbon dioxide, sterile bandages and records for electrical transcription.

FLUIDS SHIPPING AND STORAGE

MANY TYPES of containers may be used for the storage and shipment of chemicals. Some of the most commonly met with for handling fluids are: carboys; drums; cylinders; tank trucks, trailers and semi-trailers; tank cars; tanks and gas holders. And there are numerous modifications of each of these which have been designed to meet certain requirements of the chemical producers and shippers.

Carboys and drums have been thoroughly discussed by R. W. Lahey in previous issues of *Chem. & Met.* In the case of carboys the reader is referred to Vol. 43, p. 132 and Vol. 44, p. 144 for information, and in the case of drums to Vol. 43, p. 486 and p. 598.

Cylinders and Tank Trucks

CYLINDERS are divided into three classes, those for low pressures (I.C.C. 4A master specification), those for high pressures (I.C.C. 3A master specification) and the anhydrous ammonia cylinder (I.C.C. 4). The first class is used for the shipment of propane, butane, methyl chloride, hydrogen sulphide, propylene and sulphur dioxide. The high-pressure cylinders are employed for oxygen, hydrogen, nitrogen, carbon dioxide, nitrous oxide and medical oxygen and of course any of the low-pressure gases.

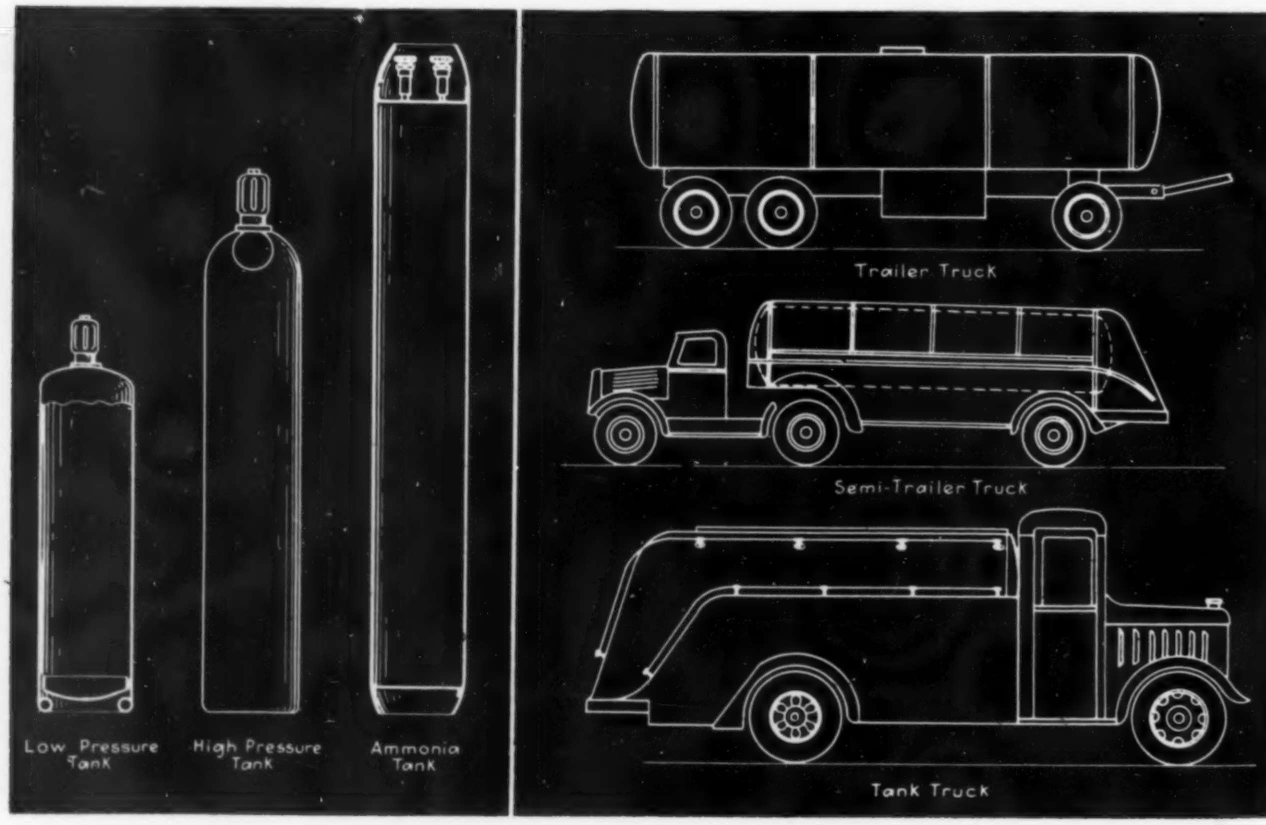
A recent development in containers is the automobile tank truck, trailer and semi-trailer. This means of shipping chemicals has been found convenient when the distance is not great and when speed is essential. These tanks are custom built to suit the special conditions required by the chemical manufacturer.

Ordinary steel tanks are quite satisfactory for many of the chemicals handled, but in other cases the tanks must be constructed from special metals and alloys in order to prevent contamination or corrosion. In those cases where the chemical may not contact the metal of the tank they are usually lined or coated. The linings may be made from one of the special metallic materials, from a rubber coating, varnish or glass. Tanks may be insulated when it is necessary to prevent raising or lowering of the temperature of the contents. Other tanks are equipped with heater coils which assist in the unloading of the material transported.

Much use has been made of this form of transportation for butane and propane. One butane tank truck and trailer system in daily use has a combined capacity of 5,500 gal. An interesting feature of the butane system is that the vapor remaining in the tanks after unloading, which is equivalent to about 100 gal., is used as motor fuel on the return trip. The main truck tank has a capacity of 2,500 gal. and is of welded construction with a working capacity of 125 lb. per sq.in. The trailer holds 3,000 gal. and is of riveted construction.

The trailer that is shown here has a capacity of 3,200 gal. and is welded construction which allows for an increased payload. It has an inverted dome in which vapor equalizing valve, slip gage, safety valve, etc., are mounted. In another case a 5,000 gal. tank is used mounted on a semi-trailer chassis.

Likewise, a large number of other products are shipped in tank trucks, trailers, and semi-trailers. The list includes gasoline, propane, petroleum, syrup, linseed oil, newsprint ink, soybean oil, corn oil, etc.



Storage Tanks

ORDINARY CYLINDRICAL STEEL TANKS with cone roofs are used to store water and other heavy or non-volatile liquids where evaporation loss is not a factor. The increasing importance of fire prevention and of reducing evaporation losses from storage tanks has led to the development of special types of tank roofs. The Wiggins floating roof prevents air coming into contact with volatile liquids. It floats directly on the surface of the liquid and eliminates all vapor space except in a narrow circumferential section which is closed by means of a sliding seal in contact with the tank shell. This roof effectively reduces evaporation losses, minimizes the corrosive effect of sulphurous crude oils on steel and is probably the most important single means of reducing the fire hazards in an oil plant.

Flat bottom storage tanks with Wiggins breather roofs and balloon roofs are used extensively to store volatile liquids which do not boil at atmospheric temperatures when the contents of the tank are held in standing storage for long periods of time. The breather roof is, in effect, a flexible steel diaphragm across the top of a storage tank. This diaphragm is welded to the top of the tank shell and rests on a special type of roof framing when in the down position. It is fastened to the framing, however, and flexes up and down as the air vapor mixture in the tank expands and contracts. Breathing losses are reduced or prevented according to temperature changes and the quantity of liquid stored in the tank. By operating the breather roof with the oil in contact with the roof plating, all vapor space is eliminated, the storage capacity is increased and corrosion of the underside of the plating is minimized.

The Wiggins balloon roof is a logical growth of the breather roof. The excellent results secured with the latter on standing storage led quite naturally to the search for a roof operating on the same principle but having sufficient capacity to prevent all breathing loss not only on full standing tanks but also on tanks which are frequently filled and emptied.

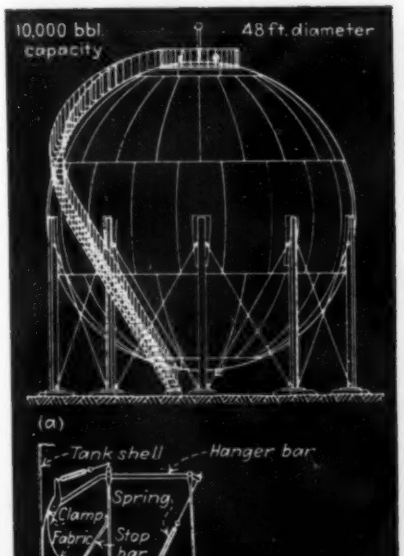
Flat bottom steel tanks with Wiggins pontoon roofs are used to store crude oil, gasoline and other volatile liquids which do not boil at atmospheric temperatures. This type of installation is used largely where tanks are worked; in other words, where the tank is being filled and emptied constantly. The pontoon roof rides directly on the surface of the liquid preventing filling and breathing evaporation losses and eliminating a considerable portion of the fire hazard.

The pontoon roof is applicable to riveted or welded tanks 15 ft. in diameter or larger. It may be used at pipeline stations, refineries, bulk stations and marine terminals. It can be furnished with new tanks or installed in existing tanks.

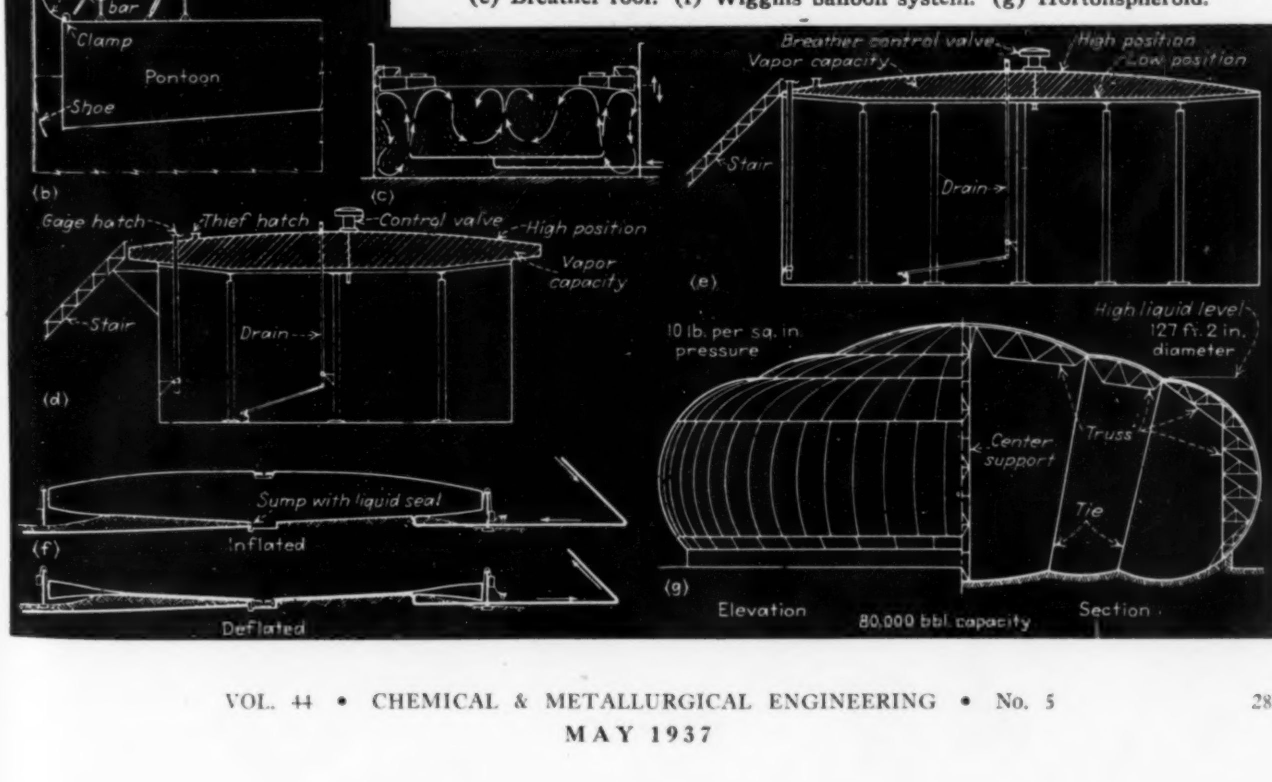
Liquids such as butane, propane and gasoline which boil at atmospheric pressures are most satisfactorily stored under pressure. The Hortonspheroid has been developed to store liquids under pressures up to 20 lb. per sq. in. It is designed in spheroidal form with the particular aim of resisting the stresses due to integral gas pressure and liquid load without undue distortion, and of utilizing the entire sectional area of the shell plating to resist the liquid load.

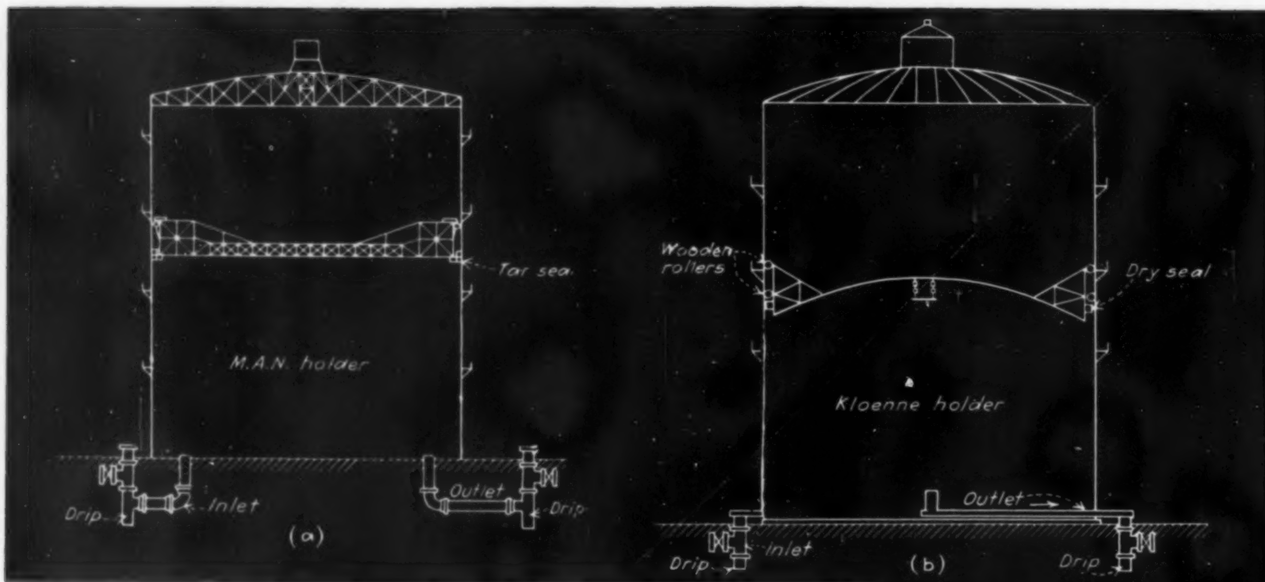
The Hortensphere is spherical in shape and is used to store extremely volatile products, at pressures of 20 lb. per sq.in. or higher. It is built in capacities ranging from 2,500 bbl. to 12,500 bbl. It is designed with a factor of safety of four against structural failure.

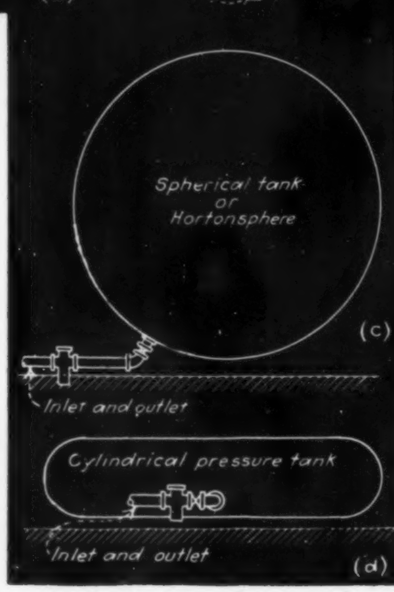
For further information about the Wiggins roofs and Horton tanks refer to *Chem. & Met.*, Vol. 43, p. 426, 1936.



(a) Hortonsphere for high pressures. (b) Section of Wiggins pontoon roof seal used with riveted and lap welded tank shells. (c) Circulation during blending operation in tank equipped with a pontoon roof. (d) Balloon roof. (e) Breather roof. (f) Wiggins balloon system. (g) Hortonspheroid.







(a) Tar-sealed M.A.N. holder is available in sizes up to 20,000,000 cu.ft. (b) The Kloenne holder is dry sealed. (c) and (d) These are fixed volume, variable pressure holders

Gas Storage

By JEROME J. MORGAN
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THE STORAGE of gases, which are corrosive or which are soluble in water or other confining liquids, offers special difficulties. For the storage of other gases in the chemical industries use may be made of a suitable type from the gas holders developed for storage in the fuel gas industry. A convenient classification of such holders is as follows:

A. Low pressure—variable volume holders
- 1. Water-sealed
  - a. Simple or single lift
  - b. Multiple lift, telescopic
- 2. Waterless
  - a. Tar-sealed
  - b. Dry seal

B. High pressure—constant volume, variable pressure holders
- 1. Cylindrical
  - a. Vertical
  - b. Horizontal
- 2. Spherical

A diagrammatic sketch of a telescopic water-sealed holder is shown. The single lift holder consists of an inverted bell which dips into a tank of water so that it is free to rise or fall according to the amount of gas confined in it. A guide frame to prevent the bell from toppling over as it ascends, and pipes to introduce and draw off the gas above the level of the water are also provided. This holder uses the principle of the laboratory gasometer which was discovered by Lavoisier in 1781. In this type it is evident that the depth of water in the tank must be equal to the height of the bell, but of course, the volume of water, may be greatly decreased by use of a covered cylinder in the center so that the water is mostly contained in the annular channel around this cylinder which is shown dotted in diagram (e). To increase the volume of the holder without increasing the depth of the tank other lifts, of which two are shown in diagram (e), are used. These are cylindrical shells open at both top and bottom and fabricated as shown, with cups at the bottom and grips at the top.

The method of operation is simple. As more gas enters the holder the bell rises entirely out of the water, but as it rises its cup engages the grip at the top of the next lift. As this lift rises water from the tank is caught in the cup into which the grip dips and forms a seal between the other two sections. When gas is withdrawn the outer lifts are disengaged and submerged beneath the water in the tank, but remain ready for immediate use as described, if more gas enters the holder. A guide frame not shown, is engaged by guide rollers attached to the different sections to keep them in position vertically when filled with gas.

Water-sealed holders have the advantages of simplicity in operation and require little attention except that necessary for lubrication of moving parts and maintenance of the water seals. In cold weather the water must be kept from freezing. In large sizes the weight of water in the tank requires secure foundations.

The tar-sealed M.A.N. holder illustrated in diagram (a) was developed in Germany, but is built in this country in sizes up to 20,000,000 cu.ft. It consists of a fixed polygonal shell in which gas is confined by a piston which moves up and down floating on the gas underneath. This piston is trussed for rigidity and guided by rollers to maintain it in a horizontal position. The joint

between the piston and the holder wall is made gas tight by a tar seal as shown in the accompanying diagram (a). Some tar from the seal runs down the side of the holder and is caught by a dam around the base. From here it is pumped back to maintain the proper level in the seal.

Tar-sealed holders have the advantages of: simpler foundation on account of elimination of the weight of the water tank; no freezing of water in tank and cups; improved appearance of structure; less maintenance cost for painting; ease of inspection of most of the inside of shell, greater capacity on a given area and pressure of gas nearly constant for entire capacity of holder. They also cost less to construct than large size water-sealed holders, but require continual inspection to assure the maintenance of the proper seal by the tar.

Dry Seal Holder

High-Pressure Holders

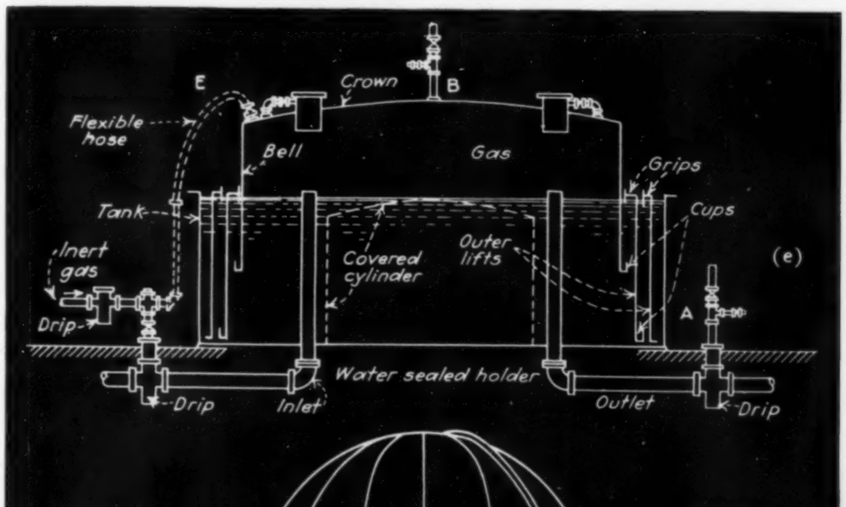
The dry seal holder shown in diagram (b) was the invention of August Kloenne of Dortmund, Germany, and is known in this country as the Stacey-Kloenne holder of which several have been constructed. It is characterized by a cylindrical shell, crowned piston and the absence of a sealing liquid. The seal between the piston and the shell is made by a packing ring which is composed of an expandable and dilatable sheet steel ring suspended by steel straps from the framework of the piston by a flexible sheet of fabric-covered corrugated lead. To the packing ring is attached a vulcanized and leather-faced fabric packing which is pressed against the inner surface of the holder shell by weighted levers, and lubricated by a special grease.

The special advantages claimed for the Kloenne holder include; the elimination of all heating, pumping, reconditioning and replacement of sealing liquid; the absence of metal to metal contacts and of any tendency of the piston to bind because the guiding is accomplished by a large number of wooden rollers. On account of low cost of maintenance and operation this type of holder is said to be particularly adaptable for small installations, but should be inspected frequently.

High Pressure Holder

When the gas in question is to be used at high pressure or when storage space is limited one of the types of fixed volume, variable pressure holders can generally be used to advantage. These differ mainly in form as shown in diagrams (c), (d) and (f), and all work on the simple principle that the volume of gas stored in a given space is directly proportional to its absolute pressure. Since these shapes maintain their form best under the high stresses to which they are subjected cylinders with hemispherical ends and spheres are commonly used in this class of holders.

(e) A telescopic water-sealed holder. This holder uses the principle of the laboratory gasometer discovered by Lavoisier. (f) Another fixed volume, variable pressure holder



Dry-Seal Holder

The advantages of high-pressure holders include: (1) There are no moving parts and no sealing liquids; (2) they occupy less space for a given capacity and harmonize better with the surroundings; (3) their cost is more nearly proportional to their capacity; and (4) they may be constructed small enough to be transported from place to place. Spherical holders have the special advantage of requiring less steel, since to withstand the same pressure a spherical shell has to be only half as thick as a cylindrical one. In the spherical holder if a joint efficiency of 78.5 per cent is assumed and a working stress of 13,750 lb. per sq.in. for steel (safety factor of 4) the weight in pounds of steel in the sphere, without including the weight of joints and supports, is equal to the storage capacity in cubic feet at 60 deg. F. and 30 in. mercury pressure. Further, the weight of steel under these conditions for a given storage capacity is independent of the pressure used, and of the number and diameter of the spheres.

For additional information see "American Gas Practice," Vol. II, Distribution and Utilization of City Gas, by J. J. Morgan, Maplewood, N. J., (1935).

Railroad Tank Cars

GREATER ECONOMY in the distribution of chemicals has encouraged the development of many modifications of the ordinary railroad tank car. Among the most important types in use are the Dry-Flo, the Wet-Flo, the car equipped inside or outside with heater coils, the insulated car, the car with a special lining and the car constructed from special metals and alloys to prevent corrosion and contamination.

The Wet-Flo railroad tank car is used to transport sugar and many other crystalline materials that are used by consumers in water solutions, or other materials such as shellacs which are used in alcohol solutions. These materials are loaded into the car in solid form and on reaching the consumer they are removed by pumping the solvent through the car, using the car as a dissolving tank. In this manner the lading travels dry with no freight paid on the solvent, and the unloading consists merely of pumping the solvent through the load. This car, therefore, provides economical transportation and unloading. The car is loaded by merely pouring the loading into it through a multiplicity of hatches along the top.

Tank cars are regularly provided with two types of heater coils. They are placed directly in the lading, so as to effect a better heat transfer and quicker unloading in the case of materials like asphalts that melt at 500 deg. F., concentrated caustic soda that melts at 200 deg. F. and viscous fluids such as blackstrap molasses, tallow, animal fats and fish oils and vegetable oils.

For ladings that must be subjected to elevated temperatures, or where any leak in a heater coil would cause serious consequences, the coils are placed outside the car tank shell, and the heat is conducted through the shell, and in some cases, through the lining of the shell.

The insulation used on the outside of a railroad car tank depends entirely on the characteristics of the lading to be carried in the car.

Railroad tank cars are regularly lined on the inside to prevent contamination of the contents. The simplest lining is a concentrated and solidified portion of the lading itself—for shipping sugar syrups, steel tanks are used, and the inside of the steel shell is coated with concentrated syrup to keep the syrup away from the shell.

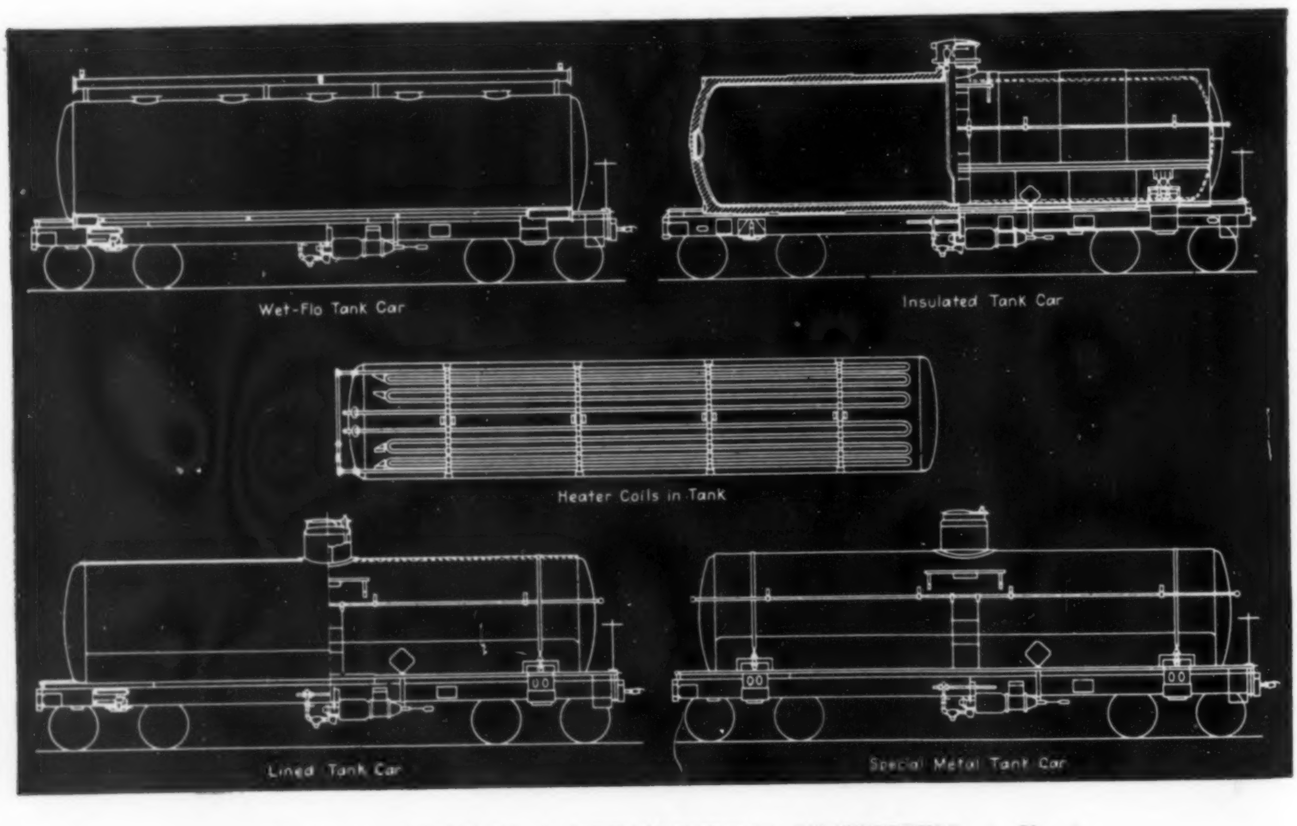
There are a great many paints, varnishes, lacquers and resins applied to the interior of steel car tanks that permit the handling of commodities without contamination from the steel.

Rubber is vulcanized to the interior of a steel tank car shell to permit successful transportation of formaldehyde, phosphoric acid or hydrochloric acid. Glass lined tank cars are used for transporting chemicals. One concern is using a car built under the I.C.C. Regulation 103-AW for chlorosulphonic acid. The design complies with the specifications of the Bureau of Explosives. Other materials conveyed in glass lined cars include glucose, wine, brandy and milk.

Nickel is rolled on to steel sheets which are fabricated into car tanks exposing an interior surface of nickel only to ladings such as phenol, water-white turpentine and low-iron caustic soda.

Within recent years newer materials have become available to car builders, and railroad car tanks are now regularly constructed of them. Aluminum alloy tank cars are used for shipping hydrogen peroxide, acetic acid, glycerine, etc. Stainless steels are available in a wide variety and are used to make car tanks for handling nitric acid, formaldehyde and special alcohols. Monel metal, copper and its many alloys, Dowmetal, etc., have special properties advantageous to the transportation of certain commodities and are being actively discussed and considered.

The multiple-unit tank car is used for shipping sulphur dioxide, chlorine, methyl chlorine and some few other gases.



Chemical Engineering NEWS

A. I. CH. E.
WILL HOLD SEMI-ANNUAL MEETING IN TORONTO, MAY 26-28

RETURNING to Canada after a ten-year absence, the American Institute of Chemical Engineers will hold its 29th semi-annual meeting in Toronto, May 26, 27 and 28. Headquarters will be at the Royal York Hotel, and a series of interesting side trips are planned to the El Dorado Gold Mines, Ltd. and the Radium Refining Plant at Port Hope, Ont., with optional visits provided to the International Nickel Company's refinery at Copper Cliff, Ont., the Gatineau mill of the International Paper Co. at Ottawa, and the Howard Smith Paper Mills, Ltd. at Cornwall.

Dr. Albert E. R. Westman of the Ontario Research Foundation is active chairman of the local committee, serving under the honorary chairmanship of Professor J. Watson Bain of the University of Toronto. Four technical sessions have been planned at which approximately 20 papers on theoretical and applied chemical engineering are to be presented and discussed. Pre-prints of a number of these are available, but all have been abstracted into brief summaries which are included in the printed program—an innovation being tried out experimentally for the Toronto meeting.

Some of the papers to be presented at the Applied Chemical Engineering sessions include: "Chemical Engineering in the Heavy Leather Industry" by E. H. Smith, Beardmore & Co., Octon, Ont.; "Recent Developments in the Chemical Industry of Canada" by H. DeBlois and G. S. Whitby of Canadian Industries, Ltd., and National Research Council; "Extraction of Radium From Ores" by M. Ponchon, El Dorado Gold Mines, Ltd., Port Hope, Ont.; "Use of Pyrites Concentrates in Sulphite Pulp Manufacture" by Horace Freeman, Consolidated Paper Co., Three Rivers; "The Preparation of Insulin," by D. A. Scott, Connaught Laboratories; "The Drying of Granular Solids" by O. A. Hougen and N. A. Ceaglske of the University of Wisconsin; and "The Design of Equipment for Fractional Batch Distillation" by Marcel J. Bogart, The Lummus Co., New York.

Three papers from Professor W. L. Badger and his associates at the University of Michigan will be one of the features of a heat transfer symposium in the Friday session on Principles of Chemical Engineering. Other papers at these sessions come from the laboratories of the Pennsylvania State College, the University of Oklahoma, Cornell University, and the Experimental Station of the du Pont Company at Wilmington.

The local committee calls attention to the fact that all non-Americans and naturalized citizens of the United States must have passports or other identification papers to enable them to return to the United States.

Mr. Johnson at present holds the Molybdenum Co.'s fellowship in metallurgy at Carnegie Institute.

Technical sessions of the Society's annual meeting will be reviewed in the June issue of *Chem. & Met.*

Dr. Wallace H. Carothers Dies Suddenly

DR. WALLACE H. CAROTHERS, one of the most brilliant research chemists in this country, was found dead in a hotel room in Philadelphia on April 29. A few grains of poison and a squeezed lemon found near the body made it appear that he had drunk the poison in lemon juice.

Dr. Carothers was employed in research work for E. I. du Pont de Nemours & Co., at Wilmington, where he was one of the contributors to the development of "Neoprene." Before joining the du Pont research staff in 1928, he taught chemistry at Tarkio College, the University of South Dakota, University of Illinois and Harvard.

Dr. Carothers was also a leader in the development of synthetic fibers. In 1933 he was editor of *Organic Synthesis* and since 1930 had been associate editor of the *Journal of the American Chemistry Society*. He had contributed many articles to other scientific publications.

F.T.C. Dismisses Complaint Against Nitrate Interests

ON April 26 the Federal Trade Commission dismissed its complaint against the Chilean Nitrate Sales Corp., and the Chilean Nitrate Educational Bureau, Inc.

The complaint was dismissed upon execution of a stipulation with the Commission by the respondent corporations, in which they agreed not to exhibit or circulate a motion picture entitled "Minor elements and natural salts in plant nutrition," or a pamphlet entitled "Vital Impurities, the fascinating story of Chilean natural nitrate, the only nitrogen that comes from the ground.'"

Electrochemists Elect New Officers

AT THE annual meeting of the Electrochemical Society held in Philadelphia April 28—May 1, William G. Harvey of the Aluminum Co. of America, Cleveland was elected president for the ensuing year. Other officers elected were: L. D. Vorce, New York, R. L. Baldwin, Niagara Falls, and O. W. Storey, Chicago, vice-presidents; W. W. Winship, New York, E. M. Baker, Ann Arbor, Mich., and S. Swann, Jr., Urbana, Ill., managers: Robert M. Burns, New York, treasurer; and Colin G. Fink, Columbia University, New York, secretary.

The Society awarded the Acheson Medal and $1,000 Prize to Dr. Frederick Mark Becket, president of Union Carbide and Carbon Research Laboratories, Inc., and vice-president of the Electro Metallurgical Co. and of Union Carbide Co.

The Weston Fellowship of $1,000 was given to Garth L. Putnam of Seattle, Wash., who will continue his research at Columbia University. The Society's Prize to Young Authors was awarded to William A. Johnson of Pittsburgh.

Canadian Chemical Meeting At Vancouver

A SPECIAL train has been arranged to leave Toronto on Friday morning June 11, for the accommodation of those who want to leave from that vicinity to attend the convention of the Canadian Chemical Association to be held at Vancouver, June 17-19. Visits will be paid enroute to the plants of International Nickel Co., Consolidated Smelting Co., and Kimberly Mines.

The program for the Vancouver meeting lists a number of papers dealing with industrial chemistry and industrial agricultural chemistry. Considerable attention also will be given to studies on Canadian fisheries. Plant visits will include Fraser Mills and the British Columbia Packers salmon canning plant.

Arrangements for attending the convention may be made through Dr. R. T. Elworthy, 366 Adelaide St., West, Toronto, Canada.

Student Chapters Meet At Georgia Tech

THE first regional meeting of the A.I.Ch.E. student chapters of the southern schools was held at Georgia Tech. in Atlanta, April 23 and 24. Despite the long distances between schools, seven colleges were represented by 65 students and eleven faculty members.

The registrations from the attending schools were—University of Alabama, 12; Alabama Polytechnic Institute, 3; University of Florida, 10; Georgia School of Technology, 30; University of Louisville, 5; Mississippi State College, 4; University of Tennessee, 12.

The first session was held Friday, April 23 at 9:00 A.M. President M. L. Brittain of Georgia Tech. welcomed the conference members. Papers by student authors were read the remainder of the morning. Plant inspection trips were arranged for the afternoon. The technical sessions were concluded Saturday morning by a business session and more student papers.

Fifteen papers were presented in competition for two prizes offered by Dr. H. A. Curtis. First prize went to Gerald L. Veeneman of Louisville with a paper on "Laboratory Fluid Flow Apparatus." Harry G. Cooke of Tennessee took second prize with a study on "The Effect of pH on the Settling Rate of Kaolin." Two honorable mentions were given for papers by W. S. Sachs and D. W. Reed (Tennessee) on "The Influence of Freight Rate Structures on the Process Industries of the South" and W. A. Ostner (Florida) on "Application of Chemical Engineering to Brewing."

Arrangements for a second southern student meeting to be held at the University of Tennessee in Knoxville in 1938 were authorized. Committees representing the student chapters and the faculty were appointed.

This first southern student conference marked the dedication of the new chemical engineering building at Georgia Tech.

Beware of Picture Racket

If you should receive a telephone call or a visit from anyone who claims to be a photographer engaged by *Chem. & Met.* or McGraw-Hill Publishing Co., to take your personal photograph, do not be misled, as *Chem. & Met.* or McGraw-Hill Publishing Co. does not use such methods to secure photographs of individuals.

Marketing Organization For Naval Stores

AT a meeting of producers held at Waycross, Ga., on April 29, The Turpentine Farmers Trading Co. was formed. The new organization will work to improve conditions in the naval stores industry. O. T. McIntosh, president of the Southern Naval Stores Co., at Savannah was elected president of the new company. Other officers include: C. M. Gordon of Glennwood, M. C. Stallworth of Mobile, J. Edgar Dyal of Baxley and Harley Langdale of Valdosta, vice-presidents; O. W. Jackson of Savannah, acting secretary-treasurer. The directors include the president and the four vice-presidents, also N. E. Jayner of Screven, Charles Gillican of Homerville, M. Autrey of Valdosta and J. M. Wilson of Jacksonville.

The trading company is acquiring members on a payment basis of one dollar for every barrel of turpentine produced in the 1937 season with a 100-barrel minimum. For this payment the producer-member acquires a proportionate stock interest in the new company. The money thus raised will be used to carry on operations, principally to buy stocks of turpentine when prices are low and to dispose of them when the market becomes favorable.

A.S.T.M. Annual Meeting Will Be Held in New York

DURING the week of June 28–July 2, the Fortieth Annual Meeting of the American Society for Testing Materials will be held at the Waldorf-Astoria, New York. Throughout the week there will also be in progress the Fourth Exhibit of Testing Apparatus and Related Equipment. This will be the second meeting which the A.S.T.M has held in New York City, the previous one having been there in 1912 during an international congress on testing materials.

In order to provide ample time for the presentation and discussion of the large number of papers and reports scheduled, upwards of twenty formal sessions are being developed. Some of these will be devoted entirely to symposiums comprising several groups of papers. Among the groups of papers are a Symposium on Significance of Tests of Coal and Coke, another on Correlation of Laboratory and Service Tests of Paints, and one on Consistency: Critical Discussion of Present-Day Practice in Consistency Measurements. There will be an extensive series of papers on asphalt, and several on water and on cast iron.

Pulp and Paper Men Will Meet in Vancouver

SOME of the outstanding figures in the pulp and paper industry of Canada and the United States are expected to come to Vancouver, B. C. this summer to attend sessions of the Pacific Coast division of the American Pulp & Paper Mill Superintendents' Association and the Pacific section of TAPPI, the techinical organization of the pulp and paper business. The meetings will be held at Hotel Vancouver on June 11 and 12.

Ray C. Onkels of the Westminster Paper Company, chairman of the Pacific Coast division of the Superintendents' Association, and Andreas Christensen of the B. C. Pulp & Paper Co., of the executive committee of TAPPI, are the chairmen in charge of arrangements for the joint meeting.

The fact that the Canadian Chemical Association will meet in Vancouver about the same time is expected to be an added inducement for pulp men to come from the East as they will be able to attend both the pulp and paper and the chemical sessions.

Chemical Engineering NEWS

Japan Led in Chemical Developments Last Year

JAPAN probably surpassed all other countries in the number of new products introduced in 1936, the number of chemicals made for the first time in the country, and new-plant construction and expansion, according to the Department of Commerce.

Results of the intensive research which is being carried on in Japan are evidenced by the introduction of two new dyes for the printing ink industry during the year, a non-coloring enamel, a new azo dye, a fumigant, a chemical known as "Sofna" which is used for softening food, a smallpox vaccine, a sleeping sickness serum, and a new worm expellent.

A number of new processes were reported including a method of making glaubers salt, a process of treating residual brines with aluminum sulphate to yield a commercial potassium sulphate, and another which, it is claimed, permits the recovery of 95 per cent of the potash content of molasses.

One company, following a period of research and experimental production, was reported ready to start commercial production of urea by a new process, another developed a process for preparing colloidal sulphur, and an experiment station was working on a project for tanning and dyeing rabbit skins by the use of acid color.

The Japanese Government Laboratory which has been conducting research for several years on the problem of producing salt for soda ash manufacture directly from sea brine reported that, from a laboratory standpoint, experiments had reached a successful conclusion, as well as those for producing soda ash from salt.

Germany Renews Nitrate Agreement With Chile

NOTWITHSTANDING Germany's immense capacity for producing synthetic nitrogen it permits the importation of Chilean nitrate to the extent of approximately 3½ per cent of its domestic requirements, according to a report from Consul Sydney B. Redecker, Frankfort-on-Main.

Under the terms of the agreement which has just been renewed Germany agrees to admit, free of duty, a total of 80,000 metric tons of sodium nitrate during the year ending June 30, 1937, and an additional 80,000 tons in the fiscal year 1937-38.

This renewed agreement represents an alteration of the last modified agreement which granted Chile a duty-free import quota of 99,504 metric tons of sodium nitrate. The original quota of 80,000 metric tons for the year 1934-5 was increased to 86,120 tons and during 1935-36 it was advanced further to 99,504, in order to bring it into percentual alignment with the increase in Germany's total consumption.

Under the terms of Germany's bilateral trade agreement with Chile the proceeds from Germany's nitrate purchases are blocked in German marks and made available solely for the purchase of German merchandise, and in consequence of this arrangement Germany has been able to expand its export trade with Chile during recent years.

CALENDAR

THIRD DEARBORN CONFERENCE OF AGRICULTURE AND INDUSTRY, Detroit and Dearborn, Mich., May 25-27.

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS, semi-annual meeting, Toronto, Canada, May 26-28.

AMERICAN PETROLEUM INSTITUTE, mid-year meeting, Colorado Springs, Colo., June 1-3.

WORLD PETROLEUM CONGRESS, Paris, France, June 14-19.

AMERICAN SOCIETY FOR TESTING MATERIALS, annual meeting, Waldorf-Astoria Hotel, New York City, June 28 to July 2.

ACHEMA VIII, German chemical equipment exposition, Frankfort-on-Main, Germany, July 2-11.

AMERICAN CHEMICAL SOCIETY, semi-annual meeting, Rochester, N. Y., September 6-10.

TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRY, fall meeting, Savannah, Ga., October 18-20.

16TH CHEMICAL EXPOSITION, Grand Central Palace, New York City, December 6-11.

Lalor Foundation Makes First Awards

THE Lalor Foundation, organized in 1935 for the advancement of scientific research, has announced the recipients of its awards for the academic year 1937-38. These are the first grants made by the Foundation and comprise four fellowship awards of $2500 each for research in chemistry.

The appointments are: James English, Jr., Ph.D. Yale University and research assistant at California Institute of Technology, to continue research at the California Institute of Technology on the isolation and constitution of certain hormones promoting plant growth; Leland John Haworth, Ph.D. University of Wisconsin and instructor of physics at the University of Wisconsin, to conduct research in the Research Laboratory of Physical Chemistry at the Massachusetts Institute of Technology on the magnetic properties of materials at very low temperatures; Philip Albert Leighton, Ph.D. Harvard University and associate professor of physical chemistry at Stanford University, on leave of absence to conduct research in England and at Harvard University on the properties of free atoms and radicals produced during chemical and photochemical reactions; and Earl Albert Long, Ph.D. University of Ohio and instructor in chemistry at the University of California, to conduct research at the University of California on the properties of radio-active sodium and radio-active phosphorus.

Two additional candidates were also recommended for fellowship awards; namely, Dr. Eric G. Ball, associate professor of physiological chemistry at Johns Hopkins University and Dr. Nelson R. Trenner, instructor in chemistry at Princeton University.

Papers on Bulk Packaging Ready for Distribution

AT the Seventh Packaging, Packing and Shipping Conference and Exposition held at the Pennsylvania Hotel, New York on March 23-25, a symposium on Bulk Packaging held a prominent place on the program. A stenographic report of the papers read at that symposium is now available and may be had by applying to the American Management Association, 330 West 42nd St., under whose auspices the conference was held.

Chemical ECONOMICS and MARKETS

SHIPMENTS OF CHEMICALS CONTINUE ON BROAD SCALE

PRODUCTIVE activities in the industries which are large consumers of chemicals are holding at a high rate. The steel, automotive, textile, rayon, glass, ceramic, rubber, paint and varnish industries have been absorbing large amounts of raw materials. This condition is reflected in reports of a steady movement of chemicals from producing points.

Figures now at hand for the first quarter of this year to express in definite terms, the percentage gains for the quarter compared with the corresponding quarter of last year. These gains include: silk, 14.5 per cent; cotton, 28 per cent; rubber consumed, 18.8 per cent; rubber reclaimed, 37.5 per cent; automobiles, 15.4 per cent; artificial leather, 56.3 per cent; alcohol denatured, 5.6 per cent; glass containers, 21.8 per cent. Plate glass production was very low in January but since the output has been speeded up and total production for the quarter was only 3.1 per cent below the 1936 quarter.

Reports have been current to the effect that the high rate of activity in manufacturing lines so far this year has not been in keeping with the volume of sales and that stock accumulations have resulted. This may be true for some industries but there is little evidence of this in the lines into which chemicals enter in a large way.

The general price tone was a little easier in the last month but this was due to changes in some of the less important products. It does not indicate any trend as basic chemicals for the most part are in a strong position and price reductions appear less probable than price advances.

Vegetable oils were under selling pressure and this applied not only to domestic oils but also to those of foreign origin. For instance, palm oil which had previously been held at high prices was offered freely at large discounts from the old levels. Linseed oil was quotably unchanged but resale lots have appeared on the market in the last two months and tended to take the edge off prices. In the entire commodity list there has been a shaking out of speculative longs and this movement appears to have run its course with the result that the statistical position of most commodity markets has been improved.

Among developments in foreign markets was the report that the Czechoslovanian Alcohol Cartel reports that sales during the six months ended with February 28 of the current year aggregated 25,000,000 gallons against sales of 23,000,000 during the same period a year earlier. The increase was accounted for by larger sales to motor fuel blenders.

Turkey's two sulphur mines are reported to have been working full time in order to accumulate stocks. Followinr recent improvements at these mines they are stated to be in a position to supply the entire domestic demand for sulphur with the exception of certain special grades used for bleaching raisins. The use of sulphur in Turkish vineyards, the principal outlet is estimated at around 4,500 tons per annum.

The Japan Nitrogen Company is reported to have drawn up an elaborate expansion program which will necessitate an increase of 200,000,000 yen in its capitalization, according to reports from Tokyo. Practically the entire amount it is understood will be spent by a subsidiary company which will virtually control the entire chemical industry of that area. Complete details of the plan are not available but they are understood to include several projects for the generation of hydroelectric power in Chosen, an elaborate plan for coal liquefaction, doubling of the chemical fertilizer output, and monopolization of the oils and fats industry of the peninsula.

Imports of chemicals and related products reached record levels in February owing to heavy receipts of raw materials for the paint, varnish, lacquer, polish, fertilizer and medicinal industries, according to figures of the Department of Commerce.

The value of such receipts aggregated $16,700,000 compared with imports valued at $13,000,000 in January and $15,200,000 in February, 1936.

Imports of fertilizer materials were maintained at peak levels in February during which receipts aggregated 230,530 tons valued at $5,097,000—almost half the total volume and 40 per cent of the total value consisted of Chilean nitrate. During the preceding month receipts of foreign fertilizer materials were recorded at 196,461 tons.

Aluminum Salts Produced in the United States, 1935–1936

Salt	1935 Short Tons	1936 Short Tons
Alum:		
Ammonia	5,121	5,610
Potash / Other	2,685	3,070
Sodium aluminum sulphate	18,216	[1]
Aluminum chloride:		
Liquid	1,302	1,721
Crystal / Anhydrous	4,936	5,465
Aluminum sulphate:		
Commercial:		
General	335,677	373,649
Municipal	10,500	11,133
Iron-free	17,806	16,053
Other aluminum salts and hydrate	[2] 22,313	46,236
	[2] 418,556	462,937

[1] Included under "Other aluminum salts and hydrate."
[2] Revised figures.

CHEM. & MET.
Weighted Index of CHEMICAL PRICES

Base = 100 for 1927

This month	88.20
Last month	88.38
May, 1936	86.38
May, 1935	87.62

With the metal markets more stable, metal salts were less disturbed last month although the tin products showed some fluctuations in price. Acetic acid was higher but the solvents group as represented by turpentine was sharply lower.

CHEM. & MET.
Weighted Index of Prices for OILS AND FATS

Base = 100 for 1927

This month	101.68
Last month	112.10
May, 1936	82.13
May, 1935	94.14

The price trend was downward for practically all the oils and the movement extended to animal fats. Glycerine also was offered at lower prices. Linseed oil despite some resale lots held a steady price course.

Current PRICES

INDUSTRIAL CHEMICALS

	Current Price	Last Month	Last Year
Acetone, drums, lb	$0.06 -$0.07	$0.07 -$0.08	$0.9½ -$0.10
Acid, acetic, 28%, bbl., cwt	2.53 - 2.78	2.45 - 2.70	2.45 - 2.70
Glacial 99%, drums	8.70 - 8.95	8.43 - 8.68	8.43 - 8.68
U. S. P. reagent	10.75 -11.00	10.52 -10.77	10.52 -10.77
Boric, bbl., ton	105.00-115.00	105.00-115.00	105.00-115.00
Citric, kegs, lb	.25 - .28	.25 - .28	.27 - .30
Formic, bbl., ton	.11 - .11½	.11 - .11½	.11 - .11½
Gallic, tech., bbl., lb	.60 - .65	.60 - .65	.60 - .65
Hydrofluoric 30% carb., lb	.07 - .07½	.07 - .07½	.07 - .07½
Lactic, 44%, tech., light, bbl., lb	.06¼- .06¾	.06¼- .06¾	.11½- .12
Muriatic, 18°, tanks, cwt	1.00 - 1.10	1.00 - 1.10	1.00 - 1.10
Nitric, 36°, carboys, lb	.05 - .05½	.05 - .05½	.05 - .05½
Oleum, tanks, wks., ton	18.50 -20.00	18.50 -......	18.50 -20.00
Oxalic, crystals, bbl., lb	.10¾- .12	.10¾- .12	.11¾- .12¾
Phosphoric, tech., c'bys., lb	.09 - .10	.09 - .10	.09 - .10
Sulphuric, 60°, tanks, ton	11.00 -11.50	11.00 -11.50	11.00 -11.50
Sulphuric, 66°, tanks, ton	15.50 -......	15.50 -......	15.50 -......
Tannic, tech., bbl., lb	.26 - .30	.26 - .30	.23 - .35
Tartaric, powd., bbl., lb	22¾- 23¾	.22¾- .23¾	.24 - .25
Tungstic, bbl., lb	2 50 - 2.75	2.50 - 2.75	1.50 - 1.60
Alcohol, Amyl	......-......	......-......	......-......
From Pentane, tanks, lb	.123 -......	.123 -......	.15 -......
Alcohol, Butyl, tanks, lb	.08½-......	.08½-......	.08½-......
Alcohol, Ethyl, 190 p'f., bbl., gal	4.14 -......	4.14 -......	4.27½-......
Denatured, 190 proof			
No. 1 special, dr., gal wks	.32 -......	.32 -......	.33 -......
Alum, ammonia, lump, bbl., lb	.03 - .04	.03 - .04	.03 - .04
Potash, lump, bbl., lb	.05 - .04	.05 - .04	.03 - .04
Aluminum sulphate, com bags cwt	1.35 - 1.50	1.35 - 1.50	1.35 - 1.50
Iron free, bg., cwt	2.00 - 2.25	2.00 - 2.25	2.00 - 2.25
Aqua ammonia, 26°, drums, lb	.02½- .03	.02½- .03	.02½- .03
tanks, lb	.02½- .02¾	.02½- .02¾	.02½- .02¾
Ammonia, anhydrous, cyl., lb	.15½- .16	.15½- .16	.15½- .16
tanks, lb	.04½-......	.04½-......	.04½-......
Ammonium carbonate, powd tech., casks, lb	.08 - .12	.08 - .12	.08 - .12
Sulphate, wks., cwt	1.35 -......	1.35 -......	1.25 -......
Amylacetate tech., tanks, lb	.11 - .11½	.11 - .11½	.12 -......
Antimony Oxide, bbl., lb	.16 - .16½	.16 - .16½	.13½- .14
Arsenic, white, powd., bbl., lb	.03 - .03½	.03 - .03½	.03½- .04
Red, powd., kegs, lb	.15¾- .16	.15¾- .16	.15¾- .16
Barium carbonate, bbl., ton	56.50 -58.00	56.50 -58.00	56.50 -58.00
Chloride, bbl., ton	72.00 -74.00	72.00 -74.00	72.00 -74.00
Nitrate, cask, lb	.08½- .09	.08½- .09	.08½- .09
Blanc fixe, dry, bbl., lb	.03½- .04	.03½- .04	.03½- .04
Bleaching powder, f.o.b., wks., drums, cwt	2.00 - 2.10	2.00 - 2.10	2.00 - 2.10
Borax, gran., bags, ton	44.00 -49.00	44.00 -49.00	44.00 -49.00
Bromine, cs., lb	.36 - .38	.36 - .38	.36 - .38
Calcium acetate, bags	2.25 -......	2.10 -......	2.10 -......
Arsenate, dr., lb	.06¾- .07	.06¾- .07	.06 - .07
Carbide drums, lb	.05 - .06	.05 - .06	.05 - .06
Chloride, fused, dr., del., ton	20.00 -33.00	20.00 -33.00	20.00 -33.00
flake, dr., del., ton	22.00 -35.00	22.00 -35.00	22.00 -35.00
Phosphate, bbl., lb	.07½- .08	.07½- .08	.07½- .08
Carbon bisulphide, drums, lb	.05½- .06	.05½- .06	.05½- .06
Tetrachloride drums, lb	.05¾- .08½	.05¾- .06	.05½- .06
Chlorine, liquid, tanks, wks., lb	2.15 -......	2.15 -......	2.15 -......
Cylinders	.05½- .06	.05½- .06	.05½- .06
Cobalt oxide, cans, lb	1.41 - 1.51	1.41 - 1.51	1.41 - 1.51
Copperas, bgs., f.o.b., wks., ton	15.00 -16.00	15.00 -16.00	15.00 -16.00
Copper carbonate, bbl., lb	11½- .19½	.11½- .19	.11½- .16
Sulphate, bbl., cwt	5.40- 5.65	6.00 - 6.25	4.00 - 4.25
Cream of tartar, bbl., lb	.16¾- .17	.15¾- .16	.16¾- .17
Diethylene glycol, dr., lb	.16½- .20½	.16½- .20½	.16½- .20½
Epsom salt, dom., tech., bbl., cwt	1.80 - 2.00	1.80 - 2.00	1.80 - 2.00
Ethyl acetate, drums, lb	.07 -......	.07 -......	.07½-......
Formaldehyde, 40%, bbl., lb	.05¾- .06¾	.05¾- .06¾	.06 - .07
Furfural, dr., lb	.10 - .17½	.10 - .17½	.10 - .17½
Fusel oil, ref. drums, lb	.16 - .18	.16 - .18	.16 - .18
Glaubers salt, bags, cwt	.85 - 1.00	.85 - 1.00	.85 - 1.00
Glycerine, c.p., drums, extra, lb	25½-......	.31 -......	.14½- .15
Lead:			
White, basic carbonate, dry casks, lb	07½-......	.07½-......	.06½-......
White, basic sulphate, sck., lb	.07½-......	.07½-......	.06 -......
Red, dry, sck, lb	.08½-......	.08½-......	.07 -......
Lead acetate, white crys., bbl., lb	.13½- .14	13½- .14	.10½- .11
Lead arsenate, powd., bbl., lb	.11½- .12	.11½- .12	.09- .10
Lime, chem., bulk, ton	8.50 -......	8.50 -......	8.50 -......
Litharge, pwd., csk., lb	.07½-......	.07½-......	.06 -......
Lithophone, bags, lb	.04½- .04¾	.04½- .04¾	.04½- .05
Magnesium carb., tech., bags, lb	.06 - .06½	.06 - .06½	.06 - .06½

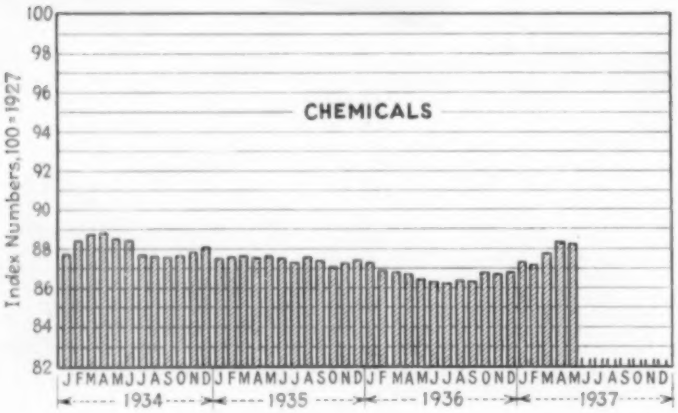
	Current Price	Last Month	Last Year
Methanol, 95%, tanks, gal	.33 -......	.33 -......	.33 -......
97%, tanks, gal	.34 -......	.34 -......	.34 -......
Synthetic, tanks, gal	.33 -......	.35½-......	.35½-......
Nickel salt, double, bbl., lb	.13 - .13½	.13 - .13½	.13 - .13½
Orange mineral, csk., lb	.11½-......	.11½-......	.10 -......
Phosphorus, red, cases, lb	.40 - .42	.40 - .42	.44 - .45
Yellow, cases, lb	.24 - .30	24 30 - .32	.28 - .32
Potassium bichromate, casks, lb	.08½- .09	.08½- .09	.08½- .09
Carbonate, 80-85%, calc. csk., lb	.07 - .07½	.07 - .07½	07 - .07½
Chlorate, powd., lb	.08½- .09	.08½- .09	08 - .08½
Hydroxide (c'stic potash) dr., lb	.07 - .07½	.07 - .07½	06½- .06½
Muriate, 80% bgs., ton	23.00 -......	23.00 -......	22.00 -......
Nitrate, bbl., lb	.05½- .06	.05½- .06	05½- .06
Permanganate, drums, lb	.18½- .19	.18½- .19	.18½- .19
Prussiate, yellow, casks, lb	.15 - .16	.15 - .16	.18 - .19
Sal ammoniac, white, casks, lb	.05 - .05½	.04½- .05	.04½- .05
Salsoda, bbl., cwt	1.00 - 1.05	1.00 - 1.05	1.00 - 1.05
Salt cake, bulk, ton	13 00 -15.00	13.00 -15.00	13.00 -15.00
Soda ash, light, 58%, bags, contract, cwt	1.23 -......	1.23 -......	1.23 -......
Dense, bags, cwt	1.25 -......	1.25 -......	1.25 -......
Soda, caustic, 76%, solid, drums contract, cwt	2.60 - 3.00	2.60 - 3 00	2.60 - 3.00
Acetate, works, bbl., lb	.04½- .05	.04½- 05	.04½- .05
Bicarbonate, bbl., cwt	1.75 - 2.00	1.75 - 2.00	1.85 - 2.00
Bichromate, casks, lb	06½- .07	.06½- 07	.06½- .07
Bisulphate, bulk, ton	15.00 -16.00	15.00 -16.00	15.00 -16.00
Bisulphite, bbl., lb	.03½- .04	.03½- 04	.03 - .04
Chlorate, kegs, lb	.06½- .06½	.06½- 06½	.06½- .06½
Chloride, tech., ton	12.00 -14.75	12.00 -14.75	12.00 -14.75
Cyanide, cases, dom., lb	.16½- .17	.16½- .17	.15½- .16
Fluoride, bbl., lb	.07½- .08	.07½- .08	.07½- .08
Hyposulphite, bbl., cwt	2.40 - 2.50	2.40 - 2.50	2.40 - 2.50
Metasilicate, bbl., cwt	2.15 - 3.15	2.15 - 3.15	2.90 - 3.00
Nitrate, bags, cwt	1.375-......	1.375-......	1.325-......
Nitrite, casks, lb	.07½- .08	07½- 08	.07½- .08
Phosphate, dibasic, bbl., lb	.022- .023	022- 023	.022- .024
Prussiate, yel. drums, lb	.10 - .11	10 - .11	.11½- .12
Silicate (40° dr.) wks., cwt	.80 - .85	80 - 85	.80 - .85
Sulphide, fused, 60-62%, dr., lb	.02¾- .03½	02¾- 03	.02¾- .03
Sulphite, crys., bbl., lb	.02¾- .02½	.02¾- 02½	.02¾- .02½
Sulphur, crude at mine, bulk, ton	18.00 -......	18.00 -......	18.00 -......
Chloride, dr., lb	.03½- .04	.03½- 04	.03½- .04
Dioxide, cyl., lb	.07 - .08	.06½- 08	.07 - .07½
Flour, bag, cwt	1.60 - 3.00	1.60 - 3 00	1.60 - 3.00
Tin Oxide, bbl., lb	.58 -......	.58 -......	.51 -......
Crystals, bbl., lb	.40 -......	.42½	.36 -......
Zinc, chloride, gran., bbl., lb	.05 - .06	.05 - .06	05 - .06
Carbonate, bbl., lb	.14 - .15	.14 - .15	09 - .11
Cyanide, dr., lb	.36 - .38	36 - 38	.36 - .38
Dust, bbl., lb	.085- .06	0 94 07	.069- .07
Zinc oxide, lead free, bag., lb	.06 -......	.06	.05 -......
5% lead sulphate, bags, lb	05½-	05½	.04½-......
Sulphate, bbl., cwt	3.15 - 3 60	3 30 - 4 50	2.65 - 3.00

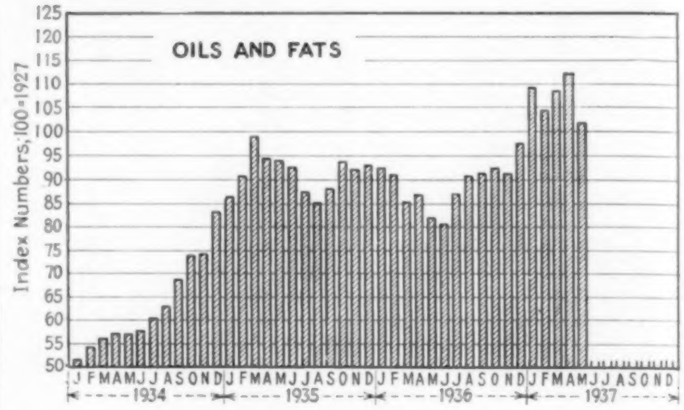
OILS AND FATS

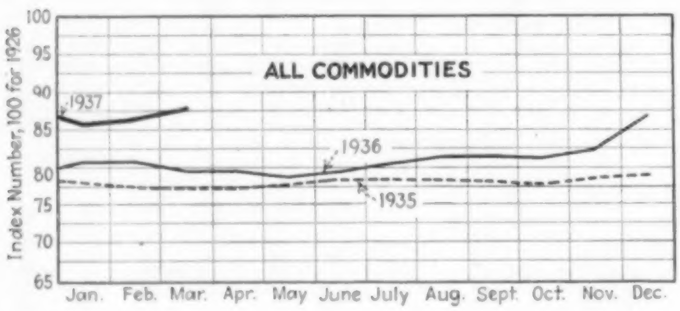
	Current Price	Last Month	Last Year
Castor oil, No. 3, bbl., lb	$0.10½-$0.11	$0.10½-$0.11	$0.10 -$0.11
Chinawood oil, bbl., lb	.14½-......	.15½-......	.18½-......
Coconut oil, Ceylon, tanks, N. Y. lb	.07½-......	.08½-......	.04 -......
Corn oil crude, tanks, (f.o.b. mill), lb	09 -......	.10½-......	.08½-......
Cottonseed oil, crude (f.o.b. mill), tanks, lb	08½-......	.09½	.07½-......
Linseed oil, raw car lots, bbl., lb	.113-......	.113-......	094-......
Palm, casks, lb	.06 -......	.07 -......	04½-......
Peanut oil, crude, tanks (mill), lb	.09½-......	.10½-......	07½-......
Rapeseed oil, refined, bbl., gal	.93 -......	.90 -......	.52 -......
Soya bean, tank, lb	.09 -......	.10 -......	.07½-......
Sulphur (olive foots), bbl., lb	.12 -......	.12 -......	.08 -......
Cod, Newfoundland, bbl., gal	.52 -......	.51 -......	.40 -......
Menhaden, light pressed, bbl., lb	.09 -......	.09 -......	.062-......
Crude, tanks (f.o.b.factory), gal	.43½-......	.45 -......	.34 -......
Grease, yellow, loose, lb	.08½-......	.08½-......	.03½-......
Oleo stearine, lb	.09½-......	.10½-......	.07½-......
Red oil, distilled, d.p. bbl., lb	.10½-......	.10½-......	.09½-......
Tallow extra, loose, lb	.08½-......	.09 -......	.04½-......

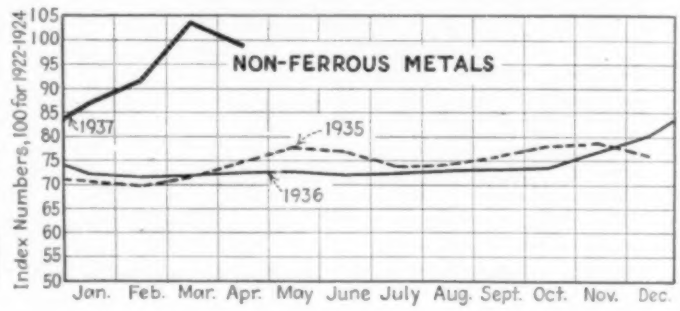
The accompanying prices refer to round lots in the New York market. Where it is the trade custom to sell f.o.b. works, quotations are given on that basis and are so designated. Prices are corrected to May 13

TRENDS OF PRODUCTION AND CONSUMPTION









COAL-TAR PRODUCTS

	Current Price	Last Month	Last Year
Alpha-napthol, crude, bbl., lb.	$0.52 –$0.55	$0.52 –$0.55	$0.60 –$0.62
Alpha-napthylamine, bbl., lb.	.32 – .34	.32 – .34	.32 – .34
Aniline oil, drums, extra, lb.	.15 – .16	.15 – .16	.14½– .15
Aniline salts, bbl., lb.	.24 – .25	.24 – .25	.24 – .25
Benzaldehyde, U.S.P., dr., lb.	1.10 – 1.25	1.10 – 1.25	1.10 – 1.25
Benzidine base, bbl., lb.	.65 – .67	.65 – .67	.65 – .67
Benzoic acid, U.S.P., kgs., lb.	.52 – .54	.52 – .54	.48 – .52
Benzyl chloride, tech., dr., lb.	.25 – .26	.25 – .26	.30 – .35
Benzol, 90%, tanks, works, gal.	.16 – .18	.16 – .18	.18 – .20
Beta-napthol, tech., drums, lb.	.23 – .24	.23 – .24	.24 – .27
Cresol, U.S.P., dr., lb.	.10 – .11	.10 – .11	.11 – .11½
Cresylic acid, 99%, dr., wks., gal.	.90 – 1.00	.77 – .85	.58 – .60
Diethylaniline, dr., lb.	.55 – .58	.55 – .58	.55 – .58
Dinitrophenol, bbl., lb.	.23 – .25	.23 – .25	.29 – .30
Dinitrotoluen, bbl., lb.	.15 – .16	.15 – .16	.16 – .17
Dip oil, 25%, dr., gal.	.23 – .25	.23 – .25	.23 – .25
Diphenylamine, bbl., lb.	.32 – .36	.32 – .36	.38 – .40
H-acid, bbl., lb.	.50 – .55	.50 – .55	.65 – .70
Naphthalene, flake, bbl., lb.	.07½– .07¾	.07½– .07¾	.07 – .08
Nitrobenzene, dr., lb.	.08½– .09	.08½– .09	.08½– .10
Para-nitraniline, bbl., lb.	.45 – .47	.45 – .47	.51 – .55
Phenol, U.S.P., drums, lb.	.13½– .14	.13½– .14	.14½– .15
Picric acid, bbl., lb.	.30 – .40	.30 – .40	.30 – .40
Pyridine, dr., gal.	1.30 – 1.35	1.30 – 1.35	1.10 – 1.15
Resorcinal, tech., kegs, lb.	.75 – .80	.75 – .80	.65 – .70
Salicylic acid, tech., bbl., lb.	.34 – .40	.34 – .40	.40 – .42
Solvent naptha, w.w., tanks, gal.	.30 –......	.30 –......	.26 –......
Tolidine, bbl., lb.	.88 – .90	.88 – .90	.88 – .90
Toluene, tanks, works, gal.	.35 –......	.35 –......	.30 –......
Xylene, com., tanks, gal.	.35 –......	.35 –......	.30 –......

MISCELLANEOUS

	Current Price	Last Month	Last Year
Barytes, grd., white, bbl., ton	$22.00–$25.00	$22.00–$25.00	$22.00–$25.00
Casein, tech., bbl., lb.	.13½– .15	.16 – .18	.14½– .16
China clay, dom., f.o.b. mine, ton.	8.00 –20.00	8.00 –20.00	8.00 –20.00
Dry colors:			
Carbon gas, black (wks.), lb.	.04 – .20	.04 – .20	.04 – .20
Prussian blue, bbl., lb.	.37 – .38	.37 – .38	.37 – .38
Ultramarine blue, bbl., lb.	.10 – .26	.10 – .26	.10 – .26
Chrome green, bbl., lb.	.26 – .27	.26 – .27	.26 – .27
Carmine red, tins, lb.	4.00 – 4.40	4.00 – 4.40	4.00 – 4.40
Para toner, lb.	.75 – .80	.75 – .80	.80 – .85
Vermilion, English, bbl., lb.	1.72 – 1.75	1.72 – 1.75	1.59 – 1.60
Chrome yellow, C. P., bbl., lb.	.13 – .14	.13 – .14	.12 – .14
Feldspar, No. 1 (f.o.b. N.C.), ton.	6.50 – 7.50	6.50 – 7.50	6.50 – 7.50
Graphite, Ceylon, lump, bbl., lb.	.06 – .06½	.07 – .08½	.07 – .08½
Gum copal Congo, bags, lb.	.08 – .30	.08 – .30	.08 – .30
Manila, bags, lb.	.08¾– .14	.08¾– .14	.08¾– .14
Damar, Batavia, cases, lb.	.15½– .23	.15½– .23	.15½– .16
Kauri cases, lb.	.17½– .60	.17½– .60	.20 – .25
Kieselguhr (f.o.b. N. Y.), ton	50.00 –55.00	50.00 –55.00	50.00 –55.00
Magnesite, calc, ton	50.00 –......	50.00 –......	50.00 –......
Pumice stone, lump, bbl., lb.	.05 – .07	.05 – .08	.05 – .07
Imported, casks, lb.	.03 – .40	.03 – .40	.03 – .35
Rosin, H., bbl.	9.55 –......	9.30 –......	5.50 –......
Turpentine, gal.	.42 –......	.41 –......	.42 –......
Shellac, orange, fine, bags, lb.	.24 –......	.25 –......	.25 –......
Bleached, bonedry, bags, lb.	.19 –......	.21 –......	.19 –......
T. N. bags, lb.	.13 –......	.14 –......	.14½–......
Soapstone (f.o.b. Vt.), bags, ton	10.00 –12.00	10.00 –12.00	10.00 –12.00
Talc, 200 mesh (f.o.b. Vt.), ton	8.00 – 8.50	8.00 – 8.50	8.00 – 8.50
300 mesh (f.o.b. Ga.), ton	7.50 –10.00	7.50 –10.00	7.50 –11.00
225 mesh (f.o.b. N. Y.), ton	13.75 –......	13.75 –......	13.75 –......

INDUSTRIAL NOTES

THOMAS C. OLIVER, for the last 25 years an officer of Chemical Construction Corp., has resigned and opened an office in the Chemists' Club Bldg., 50 E. 41st St., New York.

H. H. ROSENTHAL CO., INC., New York, has announced that Walter J. Murphy, formerly on the editorial staff of *Chemical Industries*, has become associated with the company.

NATIONAL CARBON CO., INC., Cleveland, has moved its San Francisco office to 114 Sansome St., with E. C. Friday manager.

PITTSBURGH PLATE GLASS CO., Pittsburgh, has purchased the Thresher Varnish Co. of Dayton, Ohio.

THE LINDE AIR PRODUCTS CO., New York, has opened a new oxygen plant on Powhattan Ave., Essington, Pa.

THE CHAS. TAYLOR SONS CO., Cincinnati, has appointed Edw. L. Bohn sales manager of its fire clay refractories division.

OLIVER UNITED FILTERS, INC., San Francisco, has appointed L. W. Knapp to its sales engineering staff at the New York office.

ELGIN SOFTENER CORP., Elgin, Ill., announces that William K. Clow, Jr., has joined its technical staff.

New CONSTRUCTION

Where Plants Are Being Built in Process Industries

	Current Projects — Proposed Work	Current Projects — Contracts	Cumulative 1937 — Proposed Work	Cumulative 1937 — Contracts
New England	$40,000	$85,000	$730,000	$760,000
Middle Atlantic	2,320,000	1,100,000	10,157,000	6,092,000
South	1,505,000	5,010,000	2,315,000	17,001,000
Middle West	7,480,000	510,000	10,603,000	8,572,000
West of Mississippi	230,000	247,000	7,050,000	4,146,000
Far West	....	310,000	2,800,000	4,533,000
Canada	3,475,000	....	3,805,000	371,000
Total	$15,050,000	$7,262,000	$57,460,000	$41,475,000

PROPOSED WORK

Chemical Factory—Dewey & Almy Chemical Co., Inc., Cambridge, Mass., has purchased a site on Wanklyn Ave., Ville LaSalle, Que., Can., and plans to construct a chemical factory. Estimated cost $75,000.

Chemical Factory—Merck Chemical Co., Ltd., St. Sulpice St., Montreal, Que., Can., and Lincoln Ave., Rahway, N. J., plans to rebuild its factory at Montreal recently destroyed by fire. New equipment will be purchased. Estimated cost $150,000.

Chlorine Plant—Solvay Process Co., 40 Rector St., New York, N. Y., plans to construct a chlorine plant at Baton Rouge, La., adjoining its alkali plant, on the east bank of the Mississippi River. Estimated cost $1,000,000.

Distillery—Richwood Distilling Co., Michael L. Virga, Pres., Milton, Ky., plans to recondition its distillery. Estimated cost $75,000.

Factory—Company c/o Arthur H. Hunter, Dunkirk, N. Y., plans to construct a factory at Dunkirk for the manufacture of octonol, a high grade motor fuel for the airplane transport industry, and rayon through a related process. Maturity soon.

Factory—Insulation Products Ltd., Don Mills Rd., Toronto, Ont., Can., plans to construct a plant and purchase machinery for the manufacture of rockwool. Estimated cost $50,000.

Factory—A. C. Lawrence Leather Co., Sawyer St., Peabody, Mass., is having plans prepared by Lockwood-Greene Engineers, Inc., 40 Central St., Boston, Mass., for the construction of a calfskin plant.

Glass Factory—Consolidated Plate Glass Co., Ltd., 414 St. Sulpice St., Montreal, Que., Can., plans to reconstruct its factory. Estimated cost $200,000.

Glass Factory—F. E. Reed Glass Co., 860 Maple St., Rochester, N. Y., contemplates the construction of a new annealing plant. Estimated cost including equipment will exceed $40,000.

Oil Refinery—Continental Oil Co., Lake Charles, La., through L. M. Hugh, Natchez, Miss., has announced plans for the construction of a stabilization and repression plant in the new oil field at Basile, Acadia Parish, to cost $250,000; also casing head gas plant in Gillis petroleum field in Calcasieu Parish to cost $100,000.

Paper Mill—Brown Corporation Ltd., LaTuque, Que., Can., plans to reconstruct its paper and pulp mill, also modernize its machinery. J. K. Nesbitt, c/o Owners, Archt. Estimated cost $2,000,000.

Pulp Mill—Fraser Companies Ltd., Edmundsen, N. B., Can., is having plans prepared for the construction of a pulp mill, at Sinclairs Craning, N. B. Estimated cost $500,000.

Pulp Mill—New Brunswick International Paper Co., Ltd., Dalbourne, N. B., Can., is having plans prepared for the construction of a pulp mill at Chatham, N. B. Estimated cost. $500,000.

Paper Mill—Scott Paper Co., Thomas B. McCabe, Pres., Market St., Chester, Pa., plans to construct an addition to its mill. Stone & Webster Engineering Corp., 49 Federal St., Boston, Mass., Engrs.

Pulp Mill—U. S. Lumber Co., Hattiesburg, Miss., plans to construct a pulp mill along the tracks of the Mississippi Central R. R. Estimated cost will exceed $40,000.

Rayon Mill—Duplan Silk Co., 1450 Bway., New York, N. Y., plans to construct a rayon mill at Grottoes, Va, Estimated cost will exceed $40,000.

Rayon Mill—Industrial Rayon Corp., West 98th and Walford Sts., Cleveland, O., will soon take bids for the construction of a rayon mill at Painesville, O. Wilson Watson, 4614 Prospect Ave., Cleveland, Engr. Estimated cost between $7,000,000 and $10,000,000.

Research Laboratory—Phillips Petroleum Co., Inc., Bartlesville, Okla., is having plans prepared for the construction of a research laboratory. Equipment will be purchased. Estimated cost $150,000.

Research Laboratory—Shell Petroleum Corp., 1221 Locust St., St. Louis, Mo., plans to construct a 1 story, 117x162 ft. U shaped laboratory for oil refinery.

Research Laboratory—E. R. Squibb & Sons, 745 Fifth Ave., New York, N. Y., plans to construct a 3 story, 58x110 ft. laboratory building with 2 story, 50x92 ft. wing, at New Brunswick, N. J. Estimated cost $200,000.

Sulphuric Acid Plant—E. I. Du Pont de Nemours & Co., Wilmington, Del., plans to construct a sulphuric acid recovery plant at 5311 Curtis Ave., Baltimore, Md., for the Krebs Pigment & Color Corp., a subsidiary. Estimated cost $2,000,000.

Varnish Factory—Benjamin Moore & Co., 1630 South Second St., St. Louis, Mo., plans to construct a 1 and 2 story, 61x66 ft. varnish factory. Mauran, Russell & Crowell, 1620 Chemical Bldg., St. Louis, Archts.

Varnish Factory—Pittsburgh Plate Glass Co., 235 East Pittsburgh Ave., Milwaukee, Wis., plans to construct an addition to its varnish factory. Estimated cost $180,000.

Varnish Factory—Thresher Varnish Co., 1100 Monument Ave., Dayton, O., division of Pittsburgh Plate Glass Co., Pittsburgh, Pa., plans to construct a varnish factory. Estimated cost between $300,000 and $500,000.

CONTRACTS AWARDED

Cotton Seed Oil Mill—Consumers Cotton Oil Mills, Houston and Harlingen, Tex., subsidiary of Swift & Co., Chicago, Ill., has awarded the general contract for cotton seed oil mill comprising nine buildings to Walsh & Burney, 928 North Flores St., San Antonio, at $79,155. Other work will be done by day labor. Total estimated cost $150,000.

Factory — Aluminum Corporation of America, 801 Gulf Bldg., Pittsburgh, Pa., has awarded the contract for three additions to its factory including strip mill, 81x331 ft., 157x375 ft. melting building and heat mill at Edgewater, N. J., to Consullo & Burke, 613 15th St., Union City, N. J.

Factory—The Bayer Co., Inc., Riverside Ave., Rensselaer, N. Y., has awarded the contract for a factory to W. G. Sheehan Construction Co., Inc., 28 DeWitt St., Albany. Estimated cost $40,000.

Factory—E. Berghausen Chemical Co., 915 East Carr St., Cincinnati, O., has awarded the contract for a factory to Ferro Concrete Construction Co., 203 West Third St., Cincinnati. Estimated cost $70,000.

Factory—Linde Air Products Co., 30 East 42nd St., New York, N. Y., has awarded the contract for a factory to Arthur H. Hartmann, 538 North 25th St., Milwaukee, Wis. Estimated cost including equipment $40,000.

Factory—Purex Corp., 1001 East 62nd St., Los Angeles, Calif, has awarded the contract for a factory on Compton-Jaborcria Rd., South Gate, Calif., to Ryan A. Grut, 318 West 9th St., Los Angeles. Estimated cost $60,000.

Factory—Wellman Bronze & Aluminum Co., 6017 Superior Ave., Cleveland, O., has awarded the contract for alterations and additions to its factory to H. G. Slatmyer & Son Construction Co., 203 West Lakeside Ave., Cleveland. Estimated cost $40,000.

Glass Factory—Olean Glass Co., Inc., Third and Reed Sts., Olean, N. Y., has awarded the contract for a factory on Wayen St., to F. T. Coughlin, 230 North Third St., Olean. Estimated cost will exceed $100,000.

Glass Factory—Pennsylvania Glass Bottle Co., T. E. Kirch, Plant Mgr., Sheffield, Pa., will rehabilitate its factory. Work will be done under supervision of owner. Estimated cost $200,000.

Kiln—Hales & Hunter Co., 4600 Central Ave., Chicago, Ill., has awarded the contract for a 3 story kiln building to Harvey Hanson, 1851 North Elston St., Chicago.

Laboratory—Merck & Co., Lincoln Ave., Rahway, N. J., has awarded the contract for Laboratory Building No. 50, 2 story, 50x105 ft., to Kasbro Construction Co., 60 Park Pl., Newark, N. J.

Ethyl Fluid Plant—E. I. du Pont de Nemours & Co., Wilmington, Del., will start work immediately on a $1,750,000 addition to Ethyl fluid plant now under construction at Baton Rouge, La. The addition is to a $2,800,000 plant now under construction and scheduled for completion this summer. Harry B. Fisher is Baton Rouge manager.

Oil Refinery—Bradford Oil Refining Co., H. C. Salisbury, Plant Mgr., Foster Brook (McKean Co.), Pa., has awarded the contract for a cracking plant to Alcorn Combustion Co., Bellevue Court Bldg., Philadelphia, Pa. Estimated cost $500,000.

Oil Refinery—Daugherty Refining Co., c/o L. W. Murphy, Petrolia, Pa., will construct a 2 story, 50x145 ft. barrel and shipping house. Owner will buy materials and construct by day labor.

Oil Refinery—Phoenix Refining Co., San Antonio and Bruni, Tex., will construct a crude oil skimming plant to have a capacity of 1,500 bbl. daily with provision to increasing to 2,500 bbl., at Rio Grande City, Tex. Estimated cost $45,000.

Refinery—Valvoline Oil Co., C. J. Leroux, Vice Pres. and Gen. Mgr., Fifth and Butler Sts., Cincinnati, O., will repair, alter and improve its oil refinery on South Carver St., Warren, Pa., for the manufacture of vaseline. Paris-Eaton earth burner will be installed. Work will be done by separate contracts and company forces under supervision of Robert Stanley, construction engineer for Company. Estimated cost $50,000.

Paint Factory—Magnolia Petroleum Co., c/o E. W. Gross, Mgr., Beaumont, Tex., will construct a factory for the manufacture of paint. Work will be done by owner. Estimated cost $52,000.

Paper Mill—Marathon Paper Mills Co., Menasha, Wis., has awarded the contract for an addition to its mill to James Leck Co., 513 Third Ave., N. E., Minneapolis, Minn. Estimated cost $120,000.

Paper Mill—Smith Paper Co., Mill St., Lee, Mass., has awarded the contract for an addition to Eagle Mill to Fred T. Ley & Co., Inc., 1215 Main St., Springfield, Mass. Estimated cost $40,000.

Pulp Mill—National Container Corp., Review Ave., Long Island City, N. Y., has awarded the contract for the construction of a pulp mill in Jacksonville, Fla., to Merritt, Chapman & Scott Corp., 17 Battery Pl., New York, N. Y. Estimated cost $3,260,000.

Pulp Mill—Puget Sound Pulp & Timber Co., Laurel and Bay Sts., Bellingham, Wash., has awarded the contract for a machine building to Howard S. Wright & Co., 2200 Second Ave., Seattle. Estimated cost $250,000.

Rubber Factory—Hood Rubber Co., Watertown, Mass., has awarded the contract for the construction of a factory to Fred Billings Co., 101 High St., Boston, Mass. Estimated cost $45,000.

Rubber Factory—Jersey Tire Co., New Brunswick Ave., Perth Amboy, N. J., has awarded the contract for additions and alterations to its factory to Goldfarb Bros., 64 Catalpa St., Perth Amboy.

Rubber Factory—Sun Rubber Co., M. S. Lower, Vice Pres., Barberton, O., has awarded the contract for an addition to its factory to J. L. Hunting Co., Ninth and Chester Bldg., Cleveland, O. Estimated cost $75,000.

Soap Factory—Practor & Gamble Co., 1232 West North Ave., Chicago, Ill., has awarded the contract for additions and alterations to its factory to George Nordgren Co., 189 West Madison St., Chicago, Ill. Estimated cost $40,000.

Varnish Factory—Nubian Paint & Varnish Co., 1856 North LeClaire Ave., Chicago, Ill., has awarded the contract for a factory and warehouse to E. I. Leander Co., 228 North La Salle St., Chicago. Estimated cost $125,000.

PRODUCTION OF MISCELLANEOUS CHEMICALS

Census Data for 1935 *

	1935	1933	1929
Miscellaneous chemicals, total value	$68,778,664	(1)	(1)
Acetates, total value	$13,213,813	$11,164,609	(1)
Aluminum:			
Number of establishments	4	5	
Tons (2000 pounds)[2]	175	76	(1)
Value	$30,285	$11,295	
Amyl:			
Number of establishments	10	9	11
Gallons	1,025,789	608,000	181,203
Value	$789,293	$441,592	$312,298
Butyl:			
Number of establishments	9	11	11
Gallons	5,631,056	3,763,176	4,523,863
Value	$3,686,689	$2,577,547	$5,680,155
Calcium:			
Number of establishments	26	29	49
Tons (2000 pounds)	25,860	26,042	58,163
Value	$831,356	$1,165,938	$4,695,449
Ethyl:			
Number of establishments	9	9	14
Gallons	5,563,199	5,082,213	10,932,225
Value	$2,679,195	$2,660,445	$9,006,914
Chromium:			
Number of establishments	3		
Pounds	630,023		(1)
Value	$35,171		
Lead:		$4,307,792	
Number of establishments	5		6
Pounds	3,360,067		2,084,364
Value	$252,799		$255,753
Other acetates, value	[3] $4,909,025		(1)
Chromates and bichromates	$4,768,216	$3,579,304	(1)
Sodium:			
Number of establishments	6	6	8
Tons (2000 pounds)	37,110	29,234	39,301
Value	$4,267,266	$3,280,994	$5,137,346
Potassium:			
Number of establishments	5		
Pounds	4,491,316		
Value	$359,366	$298,310	(1)
Other chromates and bichromates	$141,584		
Citrates, total value	$1,358,161	$1,463,463	(1)
Iron-ammonium:			
Number of establishments	4	3	
Pounds	304,902	132,192	(1)
Value	$123,643	$51,399	
Potassium:			
Number of establishments	3	4	5
Pounds	174,501	145,556	151,074
Value	$65,761	$63,362	$80,701
Iron:			
Number of establishments	3		
Pounds	5,785		(1)
Value	$4,223	$1,348,702	
Other citrates, value	[4] $1,164,534		
Cyanides, total value	$6,993,591	$4,866,614	(1)
Copper:			
Number of establishments	4	4	
Pounds	473,518	551,590	(1)
Value	$169,557	$209,117	
Ferric-ferro (Prussian blue):			
Number of establishments	21		21
Pounds	4,894,621		4,803,419
Value	$1,742,069		$1,446,456
Silver:		$4,657,497	
Number of establishments	5		
Ounces	130,073		(1)
Value	$77,899		
Other cyanides, value	[5] $5,004,066		(1)
Hydroxides, total value	$30,247,646	$26,006,527	(1)
Potassium (caustic):			
Number of establishments	4	4	3
Tons (2000 pounds)[6]	9,518	9,348	4,818
Value	$1,260,031	$868,000	$580,765
Sodium (caustic):			
Number of establishments	29	27	25
Total production, tons (2000 pounds)[7]	758,543	686,983	761,792
Made and consumed	39,087	42,252	37,118
Made for sale —			
Total tons	719,456	644,731	724,674
Total value	$28,104,631	$24,478,385	$36,089,264
Electrolytic:			
Number of establishments	21	21	20
Total production, tons	321,563	247,620	236,807
Made and consumed	34,797	39,114	(1)
Made for sale —			
Tons	286,766	208,506	(1)
Value	$11,233,704	$8,683,911	(1)
Lime-soda:			
Number of establishments	11	9	6
Total production, tons [8]	436,980	439,363	524,985
Made and consumed	4,290	3,138	
Made for sale —			
Tons	432,690	436,225	(1)
Value	$16,870,927	$15,794,474	
Other hydroxides, value	$882,984	$660,142	
Iodides, total value	$745,324	$1,309,237	(1)
Potassium:			
Number of establishments	7	8	7
Pounds	433,489	479,079	443,557
Value	$572,161	$1,108,316	$1,487,166
Sodium:			
Number of establishments	5	5	6
Pounds	38,024	36,775	49,796
Value	$82,038	$116,401	$214,960
Thymol:			
Number of establishments	3		
Pounds	6,615	$84,520	
Value	$21,935		(1)
Other iodides, value	$69,190		
Nitrates, total value [9]	$3,296,829	$2,603,939	(1)
Bismuth sub-.			
Number of establishments	6	6	5
Pounds	269,193	387,743	280,454
Value	$360,303	$454,575	$465,982
Silver (lunar caustic):			
Number of establishments	6	6	5
Ounces	5,144,507	4,145,648	5,646,749
Value	$1,887,693	$1,071,810	$2,015,936
Ammonium:			
Number of establishments	9	10	
Pounds	25,297,894	18,693,952	(1)
Value	$673,704	$574,056	
Zinc:			
Number of establishments	3		
Pounds	12,502	$503,498	(1)
Value	$2,594		
Other nitrates except sodium, value	$372,535		
Resinates, total value	$171,994	$69,830	(1)
Cobalt:			
Number of establishments	4		
Pounds	203,108	$69,830	(1)
Value	$37,046		
Other resinates, value	$134,248		
Stearates, total value	$1,085,219	(1)	(1)
Aluminum:			
Number of establishments	12	5	6
Tons (2000 pounds)	1,896	681	1,066
Value	$633,274	$227,466	$440,180
Calcium:			
Number of establishments	8	3	
Pounds	491,673	99,809	(1)
Value	$90,582	$16,442	
Zinc:			
Number of establishments	10		6
Pounds	1,718,979	(10)	1,454,797
Value	$322,500		$320,203
Other stearates, value	$38,863	(1)	(1)
Salicylates, total value	$200,805	$135,841	(1)
Magnesium:			
Number of establishments	3	3	
Pounds	4,420	3,602	(1)
Value	$4,866	$3,432	
Other salicylates, value	$195,939	$132,409	
Sulphides, total value	$2,084,149	$1,790,446	(1)
Sodium:			
Number of establishments	13	11	18
Tons (2000 pounds)[11]	24,757	30,732	33,032
Value	$1,362,698	$1,353,086	$1,406,606
Ammonium:			
Number of establishments	5		
Pounds (basis 100 per cent)	848,248	$436,560	(1)
Value	$85,730		
Other sulphides, value	$635,721		
Sulphites, total value	$3,745,034	$3,003,088	(1)
Sodium, normal: [12]			
Number of establishments	9	7	6
Tons (2000 pounds)	6,840	3,371	5,970
Value	$473,991	$266,339	$462,072
Sodium, formaldehyde and zinc-hydro:			
Number of establishments	7	6	
Pounds	15,076,836	12,482,486	(1)
Value	$2,650,638	$2,305,059	
Other sulphites, value	$620,405	$431,690	
Tartrates, total value	$867,883	$1,088,252	(1)
Potassium bi- (cream of tartar):			
Number of establishments	4	3	7
Pounds	3,855,022	5,789,150	7,852,559
Value	$641,971	$890,818	$1,930,577
Other tartrates, value	[13] $225,912	$197,434	(1)

[1] Not available. [2] Production in 1935, basis 20 per cent; for other years as reported, regardless of strength. [3] Includes, in order of value, data for cellulose acetate, sodium acetate, isopropyl acetate, etc. [4] Includes, in order of value, data for sodium citrate, calcium citrate, etc. [5] Includes, in order of value, data for sodium cyanide, sodium ferrocyanide, potassium ferrocyanide, and ferric cyanide, etc. [6] Production in 1935, basis 100 per cent; for other years as reported, regardless of strength. [7] Not including sodium hydroxide made and consumed in establishments classified in the wood pulp and textile industries. [8] Includes output of 2 establishments that produce caustic from natural soda ash. [9] Data for sodium nitrate withheld to avoid disclosing an approximation of the output of an individual establishment. [10] No comparable data. [11] Production in 1935, basis 60 to 62 per cent; for other years as reported, regardless of strength. [12] Anhydrous and crystal. [13] Includes, in order of value, data for Rochelle salts, tartar emetic, etc.

* Above figures give production data for Part 1, Miscellaneous Chemicals. Data for Part 2 and Part 3 will soon be released.